APPLETONS'

SCHOOL PHYSICS

EMBRACING THE RESULTS OF THE MOST RECENT RESEARCHES IN THE SEVERAL DEPARTMENTS OF NATURAL PHILOSOPHY

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NEW YORK ·:· CINCINNATI ·:· CHICAGO
AMERICAN BOOK COMPANY

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PREFACE.

THE present volume is intended to meet an existing demand for a thoroughly modern text-book on Natural Philosophy, which shall reflect the most advanced and practical laboratory and pedagogical methods, and at the same time be adapted, in style and matter, for use in the higher grades of our grammar-schools, our high-schools, and our academies. In the belief that special investigators and teachers are distinctively qualified for the purpose, the editor has assigned the different sections of the book to educators of recognized eminence and skill, governing his selection in each case by the peculiar qualifications of the author. The reputation of the several contributors, and the standing of the great scientific schools which they represent, must secure for this work a consideration accorded to few American school-texts. The sections on motion, energy, force, the properties and constitution of matter, solids, liquids, gases, and mechanics proper, were prepared by Professor Silas W. Holman, of the Massachusetts Institute of Technology; those on heat, light, frictional and voltaic electricity, by Francis E. Nipher, Professor of Physics in Washington University, St. Louis. Professor Alfred M. Mayer, of the Stevens Institute of Technology, Hoboken, N. J., furnished the chapter on sound; and Francis B. Crocker, E. M., Instructor in Electrical Engineering, School of Mines, Columbia College, the sections relating to magnetism and the practical applications of electricity. Numerous friends of the book have aided the editor with valuable suggestions and criticisms; special acknowledgment is due to Professors Rood, Trowbridge, and Rees, of Columbia College, and Professor George F. Swain, of the Massachusetts Institute of Technology.

The attention of teachers is asked to the following specific features:

The thorough and original treatment of motion, energy, force, and work. In the chapters on dynamics, the author has presented a modern and appliable conception of the nature, transformation, and conservation of energy, as well as of the relation existing between energy and force. These subjects are treated with the greatest simplicity,

precision, and thoroughness, for it is believed that a proper understanding of them lies at the base of all scientific knowledge, however far it may be pursued.

The book is adapted to students of fourteen years and upward, but by the occasional omission of an advanced paragraph, an algebraic expression, or an exceptionally difficult principle, the text becomes perfectly comprehensible to the most juvenile learners. Thus it is essentially fitted to pupils of different degrees of maturity. The easier principles may form the basis of a first year's course; while, in the second year, the student will find in the complete text additional matters which increased age and extended experience now enable him to grasp and appreciate.

It has been the aim of the authors of this volume not to teach results merely, but to show how these results have been reached as well as what practical use is made of them, and thus to inspire the learner with enthusiasm in his work of questioning Nature. Precedence is everywhere given to the practical. The steam-engine, the electric motor, the telephone, and the telegraph, even the simplest tools, are shown to be machines or devices by which energy of some form is made to do work useful to man. The experiments, especially those described in the chapters on dynamics, etc., are largely intended as illustrations, and not as proofs; hence the pupil is not led to draw extended inferences from insufficient evidence—a habit antagonistic to proper and symmetrical mental development. Further, the significance of the algebraic formulæ is immediately impressed upon the learner by solved numerical examples. This feature is of special importance in the earlier discussions, where the abstract or general statements are rendered much more intelligible because accompanied with concrete forms.

Instructive diagrams and illustrations have been introduced wherever it was thought they would relieve the text; suggestive questions, not intended to supersede minute examination by the teacher, but rather to exercise the reasoning faculties of the pupil, are inserted at such intervals as mark convenient and logical divisions into lessons; problems are appended to the several sections, to test the student's understanding of the principles therein explained; and applications of these principles in every-day experience render them delightful to learn and easy to remember.

The illustrations not only reproduce the more complicated apparatus usually found in the school laboratory, but also elucidate the descriptions of simple experiments that can be successfully attempted by young people with home-made appliances. At the beginning of

each principal section is pictured a suggestive group of such apparatus as will be found necessary to the performance of the experiments described in the chapter following; and, throughout the book, minute instructions are given for the cheap manufacture of essential pieces of apparatus.

The publishers feel assured that the many valuable features of this new School Physics must recommend it to teachers as a singularly practical and authoritative text-book on the subjects of which it treats.

NEW YORK, *March 2, 1891.*

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PHYSICS, OR NATURAL PHILOSOPHY.

PRELIMINARY STATEMENTS AND DEFINITIONS.

The Fundamental Things about which we have to learn in Physics are Matter and its Motion—matter, out of which everything is built up; motion, which gives to matter the possibility of form, structure, phenomena, and laws, and which is everywhere and unceasing.

Matter in motion possesses Energy—that which not only does all the work of the universe, but which holds every particle to its neighbor and yet keeps it apart from that neighbor.

Physical Science deals only with the phenomena and laws of matter, and of matter in motion. It does not attempt to determine whence matter and its motion came, what matter is, or how it acquired motion. It does not deny that other things than matter in motion are essential to the universe. Whatever such things there are, lie outside the scope of Physical Science.

We are everywhere surrounded by objects which form a part of what we call the physical universe. In studying them we proceed upon the suppositions or beliefs—

1. That they exist independently of ourselves, or, as we say, have *objective* existence.

2. That we perceive them and become acquainted with them solely by the aid of our senses.

3. That we are liable to misinterpret the indications of our senses.

4. That the continued exercise of Reason enables us gradually to sift the truth from the error in our interpretation of these indications.

Phenomena.—As we examine and consider the objects about us, we perceive that they differ as to size, shape, color, hardness, position, and many other characteristics or qualities. We also perceive that they are concerned in certain events or occurrences which are going on naturally, or can be made to take place. Thus, we observe that objects when dropped fall to the ground, that water on a sloping surface runs downward; that an object held up in the sunshine casts a shadow; that the sun appears to rise in the east and set in the west. These and a multitude of other events are what we call Phenomena.

Science.—But a mere examination and cataloguing of objects and phenomena would never give us a science. Science involves a study of the relations between different objects and between phenomena. These relations must be analyzed and expressed in general statements, which are called Laws. The whole body of truth thus gained, namely, the knowledge of material objects, phenomena, and relations or laws, constitutes the science called Physics, or Natural Philosophy.

Law.—Let us look a little more closely at what is meant by physical laws. If almost any object whatever be held up from the earth's surface and then be released, it will fall to the ground. From our own experience and that of others in the past, we know that every object tested in this way has fallen except where for some well-understood cause it was prevented from so doing, as, for instance, a balloon by the buoyancy of the air or a feather by the resistance of the air. We may, therefore, say that every object tested has shown a tendency to fall toward the earth.

But this statement is merely a summary of the facts or phenomena for all bodies tested, and is not a law. How

must it be changed to become one? Simply by being made general—that is, it must be expressed so as to apply to all bodies. If, then, we say *every body near the earth possesses a tendency to fall,* that is, has weight, we shall have a statement of the class which we call laws. This statement includes every body near the earth, whether it has been tested or not.

Now, how do we know that this law is true? We do not know that it is true in the same sense that we know the truth of the first statement. We can not even have the same certainty that a given object which has weight to-day will have weight to-morrow. How, then, can we have any confidence in general statements or predictions based upon past experience? And if these laws are an essential part of science, how much reliance is to be placed upon them? There certainly is such a thing as too great confidence in science, and there is a wide difference between the degrees of confidence to be given to different scientific laws. These laws are being continually developed and corrected, and the measure of confidence to which they are entitled depends on the thoroughness with which the underlying facts were examined, and in the exactness with which subsequently observed facts and phenomena have been found to coincide with the law.

The chief reason why we are disposed to put confidence in laws and predictions is our belief in the proposition that "the same causes will always produce the same effects." This is a generalized statement of our own and all past experience, viz., that the same causes have always produced the same effects, and our belief in it is measured by the breadth of experience upon which it rests.

It must be remembered that laws do not "govern" events in the sense of causing them. A law is merely the general ized statement of what has been observed to occur.

Cause and Effect.—What do these terms mean? Push a book lying on the table. It moves. Try the experiment under a variety of conditions as to time, place, temperature, and so on. You will find that the push, unless neutralized in some obvious way, always produces the motion, and that the motion does not occur without a push. You conclude, then, that it *appears* not to be simply a matter of

chance that the push and the motion occur at the same time, but that they necessarily occur together, and that the motion appears to result from the push. The push is then said to be the *cause* of the motion, and the motion the *effect* of the push.

We should feel a considerable degree of confidence, then, in making the generalized statement that the push, unless neutralized, always will produce the motion; but we should not pretend to say that this statement is absolutely true, for, besides the liability to some imperfection in our observations, we are not certain of the truth of the proposition, "the same causes always produce the same effects"; and this is an essential part of the process by which we have arrived at the general statement.

In the application of this proposition, we must bear in mind that if the cause be not precisely the same (except with respect to time), the effect will not be precisely the same; it may be extraordinarily different. For instance, a burnt-out match may be repeatedly thrust into gunpowder, with always the same effect of merely pushing aside the grains; but, if the match differs only by being slightly hotter on some occasion, the effect may be strikingly changed.

Chance.—A multitude of events which take place around us occur at times or places or in ways which, so far as we can see, are without any order or any apparent law or reason. We speak of such events as occurring by Chance; but, the more broad and accurate knowledge becomes, the more it is evident that events are orderly occurrences and capable of prediction. They appear to occur by chance, only because we do not know their causes or the laws which represent their actions. With infinite knowledge, all thought of chance would disappear.

Explanation of Phenomena and Laws.—A physical phenomenon or law is said to be explained or accounted for when it is shown to be a particular case of some more fundamental law or group of laws. By way of illustration, we

find that objects tend to fall toward the earth. We ask why—that is, we seek an explanation. Sir Isaac Newton, by a study of the motion of bodies, including that of the moon and planets, was led to deduce the law known as that of universal gravitation, viz., that every particle of matter tends to approach every other particle, the amount of the tendency depending on the amount of matter in the particles and on their distances apart. The tendency of objects to fall toward the earth is, then, a particular case of universal gravitation, and is therefore *explained.*

But we do not know why every particle tends to approach every other—that is, we have as yet no explanation of universal gravitation; we do not know any more fundamental law to which to ascribe it. Thus explanation in any case only carries us a step farther back; but that step is often of great service. Without it, knowledge would be fragmentary and disconnected.

Theory.—Hypothesis.—There are many phenomena and laws which we are not yet able to show to be special cases of more fundamental known laws—that is, to explain; but in the effort to find explanations we are continually forming suppositions and testing them to see whether they appear to afford the explanations desired. These suppositions in their earliest stages are often very crude and imperfect, and are then called Hypotheses. As they are more and more completely developed, and are shown to be more trustworthy or more probable, hypotheses are called Theories.

A hypothesis is developed into a theory by continued comparison with new facts, and by being corrected if necessary to correspond with them. The theory is verified and developed in the same way, and may eventually become so well confirmed as to be regarded as a highly probable law.

One of the best tests of a theory or law is to predict what would occur under certain new conditions or at a certain future time if the theory or law proves true, and then to bring about those conditions or

wait for that time and see whether the event occurs as predicted. If it does, the theory will be strengthened. If it does not, and we can show that the prediction was correctly made, the theory is thereby proved to be incorrect or incomplete, and should be amended. Thus the verification of the prediction of eclipses, of the apparently very irregular path of the moon among the stars, and especially of the existence of the planet Neptune, all based on the law of gravitation, greatly strengthens our belief in that law.

Theories and even crude hypotheses are often of very great service, even when they ultimately prove to be incorrect, for they aid in directing investigation and thus lead up to truth. It is hardly to be supposed that any theory now held will eventually prove to be an absolutely correct expression of the truth to which it relates; but theories are at present none the less indispensable.

Questions.—What are the fundamental things about which we learn in the study of Physics? Does physics have anything to say as to the origin of matter? of motion? of life? What forms the physical universe? Does this universe exist outside of our own thoughts? How do we perceive it? What are our senses? What enables us to separate truth from error in our observations? Define qualities; a phenomenon.

What constitutes the science of Physics? How does a science differ from a mere catalogue of facts and phenomena? What has been observed in regard to the tendency of objects to fall? Why is this not a law? State the law derived from this observed fact. Are any physical laws supposed to be certainly true? Why? For what reason do we have any confidence in them at all?

Illustrate cause and effect. What do we mean by saying that an event occurs by chance? To a mind knowing everything, could there be such a thing as chance? How, then, can any one believe it possible that the whole universe exists as a matter of chance? What do we mean by explanation? Does explanation explain? What is the relation between theory and hypothesis?

DEFINITIONS CONTINUED.

Physics, or Natural Philosophy, is that branch of human knowledge which deals with all objects, phenomena, and laws of the material or physical universe.

In the physical universe we come to recognize two, and only two, things which seem to be indestructible, and thus to exist entirely independently of us or of any operation of our senses or reason. These two things are Matter and Energy. Hence, Physics has been also called the science of matter and energy.

While physics neither denies nor affirms that there is something in the universe other than matter and energy, no complete discussion of such questions is possible without an adequate knowledge of the laws of this science.

Physics, as thus defined, is given its broadest scope. It includes almost all branches of science except mental science; but the term is generally employed in a much more limited sense. Those sciences which deal with classification only (as most of the natural history sciences), with phenomena where substances undergo changes in their properties (chemistry), or with phenomena which occur in living beings (biology)—are usually understood to be excluded when the term physics is employed.

There are also certain branches of physics proper which are more or less distinctly separated, or are not usually treated in text-books upon physics. Such are astronomy, which deals with the stars, sun, planets, nebulæ, comets, etc., their positions, motions, and laws; dynamical geology, which treats of the structure of the earth; etc.

The relations between physics, even in the more limited sense, and chemistry and biology, are extremely close. Many chemical and biological phenomena are almost purely physical, and this is true to such an extent that, without a knowledge of a large part of physics, little progress can be made either in chemistry or biology.

Time.—The earliest idea of Time probably comes from the recognition of the fact that one event occurs after another. If your memory were perfect, you could mentally place all events in your own experience in the order in which they followed one another in time; but it would be impossible for you to compare correctly two intervals of time between different events. By experience, however, you have found that there are certain natural processes which appear to go on in a uniform or rhythmical manner, such as the succession of night and day, of winter and summer, the apparent motions of the sun, stars, and moon, the swings of a pendulum, the flow of water through an orifice. By referring events to such processes, you can arrange a system by which the order of succession of all events and the relative intervals between them can be expressed.

In the actual measurement of time, we make use of the period of the earth's revolution around the sun to mark the longer interval of a year, the rotation of the earth on its axis to mark the day, and the beats of the pendulum to divide the day into parts.

Space.—We are accustomed to think of material objects as occupying definite positions with reference to one another —that is, as being at certain distances apart in certain directions. We understand that this is what is meant when we refer to the relative positions of bodies in Space.

In thinking of the distance between bodies, we do not conceive it as depending upon any material thing between them. Our idea of their distance apart would not be changed if we thought of them as separated by no material medium like air or water. This abstract idea of distance, or, as we may express it, of length, breadth, and depth, without any regard to the presence of matter, forms the basis of our idea of space.

"Absolute space is conceived as remaining always similar to itself and immovable. The arrangements of its parts can no more be altered than the order of the portions of time. To conceive them to move from their places is to conceive a place to move away from itself."

Relative Character of our Knowledge of Time and Space.—There is nothing to distinguish one portion of time from another except the different events which occur in each. Similarly, there is nothing to distinguish one part of space from another except their relation to the places of material bodies. We can not describe the time of an event without referring to some other event, or the place of a body except by reference to some other body. All our knowledge of both time and space is therefore essentially relative.

Think, for instance, of our method of stating the time of an event. We say that something occurred in 1776 A. D., on the 4th of July. We mean, first, that it occurred after the birth of Jesus Christ; secondly, that it occurred after that event by an interval measured by 1,776 whole revolutions of the earth about the sun and by a certain fraction of another revolution. Thus we ordinarily reckon the time of events

relatively to another (or standard) event, the birth of Christ, and by means of an event which is being continually and regularly repeated, viz., the revolution of the earth about the sun.

In locating bodies in space, no such universal point of reference is used as in time. Bodies or places upon or near the earth's surface are described as being at a certain distance in a certain direction from any convenient starting-point.

The exact location of any point of the earth's surface for precise work in geod'esy, geography, and astronomy, is given by latitude, longitude, and height above the sea-level. Latitude is measured by angular distance north or south of the equator; longitude, by angular distance east or west from a meridian chosen at will, as that passing through Greenwich, Paris, or Washington. Height above the sea is the vertical distance of the point above the mean level of the ocean. (See Appletons' Higher Geography, page 6; Appletons' Physical Geography, page 19.)

Matter.—On all sides of us are objects, some natural, some artificial. They are earth, water, and things made of wood, metal, woolen and cotton fibers, paper, stone, clay, etc. Not only can you see these objects, but you can feel their form by touch, and appreciate through the so-called muscular sense their hardness or softness, weight, etc. Many of them can be smelled or tasted; some can be heard giving out sounds; others are producing heat, light, electrical and magnetic effects. These objects are made up of substances which are either solids (wood, metal, stone, ice), or liquids (water, alcohol), or gases (air, nitrogen, oxygen). The only way in which we can learn about them, or find out that they exist, is by means of one or more of our senses—that is, through sight, touch, and the muscular sense, smell, taste, hearing. Some of them we can perceive in various ways; others, through only one or two of the senses.

A piece of brass, for instance, can be seen and touched, and will thus be found to have color, shape, and hardness; if it be smelled, an odor will be detected; if the tongue be touched to it, an impression will be made on the nerves of taste; if it be briskly struck against

something hard, it will be set into vibration and emit sound which can be heard. Air, on the other hand, is transparent, so that it can not be seen; it can not be perceived by the sense of touch in the same way as a solid. But when it is in motion it is called wind, and this we can feel pressing against the body; or when we are moving through air rapidly, as in running or riding, we always experience its pressure. Pure air has no odor or taste, but may be set in vibration in such a way that we hear sound. Thus, air is a material substance which can be perceived only by certain of the senses. Some gases, as chlorine and iodine, have color, taste, and odor. Study out for yourself the senses by which various objects and substances about you can be perceived—water, salt, glass, leather. What sense tells you whether an object is wet or dry?

Every object, body, or substance, which can be perceived through at least one of the senses, is a *material* object, body, or substance—that is, it is made up of Matter. Matter is that of which every conceivable substance is composed.

A definition ordinarily given is that *matter is anything which can be perceived by the senses.* This definition will serve well enough for the present state of your study. It is objectionable, because some of the sensations which we receive from matter (like heat) are due to the energy possessed by the bodies, and not to the matter solely.

Kinds of Matter.—Elements.—Are all objects and substances made up of the same kind of matter, or are there different kinds? Examination shows that the substance of which some are composed appears very different from that of others. Chemistry teaches that almost all these substances are compounds—that is, they may, by chemical processes, be separated into substances which are simpler, and these in turn may be further separated. But there is a limit to this process, for chemists find that they soon arrive at substances which can not by any known physical or chemical process be separated into others. These are then considered as simple or elementary substances, or kinds of matter, and are called the Elements, or the Chemical Elements. At present, there are about seventy elements known.

It is possible that some of the substances now thought to be elements may in the future be resolved into simpler ones, and it is conjectured that all may eventually be shown to be built up of only a single kind of matter.

Mass, or Quantity of Matter.—Lift in succession several objects—for instance, this book, a stone, a glass of water, a chair, a bit of paper. Ask yourself whether they all seem to contain the same amount or quantity of matter. Of course, you do not know the process of finding out how much each contains, but the objects are so different in weight, size, form, etc., that you at once infer it to be impossible for them all to contain equal quantities of matter—and in fact they do not.

Suppose, again, that from the same stick of wood you cut off two pieces, one much larger than the other; will they contain equal quantities of matter? Obviously not. Different objects, then, contain different quantities of matter.

When we wish to speak of the quantity of matter contained in a body, instead of using this long phrase, we say its Mass. Mass, then, means merely *quantity of matter.* If an object A contains twice as great a quantity of matter as an object B, then the mass of A is twice the mass of B. How mass is measured, will be shown later.

Density may be defined as the quantity of matter contained in a unit volume of any body or substance. Different bodies may contain different masses in the same volume, and therefore have different densities.

If we were to take portions of equal volume (say a cubic inch) of different substances—lead, wood, iron, air, water, ice—then these equal volumes would contain quite unequal quantities of matter. If we had a means of measuring these quantities (weighing will do it, as will be explained), we should know the densities of the different substances. The ratio of the density of any substance to the density of water is called its Specific Gravity. The process of determination

of density and specific gravity will be treated more fully hereafter. Any body which is of the same density in all its parts is called *homogeneous.*

Molecules.—All substances are supposed to be constituted or built up of parts which are extremely minute, far too small to be seen. Such parts are called Mol′ecules. The molecules of one kind of substance are supposed to be all alike, but those of different substances are different. The single molecules are assumed to be in turn built up of smaller parts, which are called Atoms.

The molecules are supposed not to be actually in contact as the individual pellets would be in a tumbler filled with shot, but to have spaces between them which are quite large as compared with the size of the molecules themselves. The molecules are further believed to be continually bounding to and fro at great speed, striking against their neighbors, and thus keeping open for themselves this space which surrounds them. These ideas and some of the reasons for them will be more fully discussed farther on.

QUESTIONS.—What does Physics include in its broadest meaning? Why is it called the science of matter and energy? What does Physics deny or affirm respecting the existence of anything but matter and energy in the universe? Why does Physics not enter into mental, moral, and religious questions? Does it deny the importance of these questions? How do we arrive at our first ideas of time? How is time actually measured? What is your idea of space? Why are time and space, as we can know them, purely relative? Illustrate.

Give examples of matter, and explain how you recognize matter. Is water matter? Is air? Are the odorous particles diffused through the air when roses are brought into the room? Can you perceive anything by your senses which is not matter? How is an external world known to us? Of what does touch inform us? *Of the exact form, size, and distance of bodies.* What are appreciated by the muscular sense? *Weight, resistance, etc.* On what does this sense to a great extent depend? *On the muscular nerves.* How many senses have you? Enumerate them, and specify the part each plays in revealing an objective world.

Define the term Matter. Are there different kinds of matter? How many? In what way are they discovered? State your idea of Mass. Define and illustrate Density. Do we know how matter is built up? How is it supposed to be constituted? What is a molecule? An atom? Are molecules in contact?

KINEMATICS.

MOTION, ITS DIRECTION, VELOCITY, ACCELERATION, AND COMPOSITION.

When we locate the position or describe the motion of an object, we have to consider the position or motion of its parts. It is therefore simpler, in first treating of motion, to deal with a material particle only, or a portion of matter so small that for the purposes required we need not consider its parts, but may treat it simply as a whole.

The following paragraphs contain definitions and propositions regarding mere motion, without any reference to the bodies moved, or to the forces or energy causing the motion, or produced thereby. They really pertain to a branch of pure mathematics and not of physics; this is called Kinematics (*kin-e-mat'ics*—from a Greek verb meaning *to move*). The propositions and definitions are deduced for application afterward to material bodies and systems.

Direction.—If we draw any straight line upon this paper, as, for instance, the line A B, we may think of it as having a certain direction. We mean that it makes certain angles with certain other lines, real or imaginary, to which for convenience we may choose to refer it.

For instance, the line A B makes an angle of thirty degrees with the top edge of the page, and another of sixty degrees with the side. Direction is necessarily relative for the reason that there can be no fixed points in space to refer to. We say that any other line has the same direction as A B when parallel to it. Thus, the direction of a line drawn through the point C parallel to A B would be the same as the direction of A B, and *vice versa.* Any two lines drawn through one point, and having the same direction, must of course coincide.

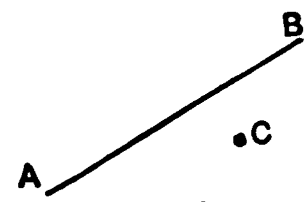

FIG. 1.

If a particle were moving from A in the direction of a line A B, it would move along that line so long as it continued to move in that direction. If a particle were at C, it could move in the direction of A B by moving in a straight line through C, and parallel to A B.

Two particles moving in parallel lines are thus said to move in the same direction. Two particles moving toward the same point are not said to move in the same direction unless the point be infinitely distant, because otherwise they can not be moving in parallel lines.

Position.—The position of any point A (Fig. 1) at a given instant of time is said to be known when its distance and direction from some suitable point B, used for reference, are known. To show the direction, we may draw a line from B to A, and state that the direction is that of this line B A; or we may state the angle which the line B A would make with certain other lines or planes used for reference.

Sometimes we locate a point by stating its perpendicular distance from three reference planes at right angles to one another. Thus, a point in a room may be located by stating its perpendicular distance above the floor, its distance from one side, and its distance from one end of the room.

From what has been said regarding our idea of space (page 8), we see that no part of space itself is different from any other part, so that there is no point in space which we can select as a starting-point. We can not, therefore, locate the position of a particle in space absolutely. All that we can do is to locate it with reference to some other particle —that is, to locate it relatively by methods just shown.

Motion is Continuous Change of Position.—If we imagine, for instance, a particle starting from A, Fig. 2, and moving on to A′, we must think of it as changing its position along some line A B C A′ (which we will call its path), and as occupying time in doing so. The particle is in motion only so long as it is *continuously* changing its position along the path—that is, so long as its position at the end of any interval of time, however short, is different from that at the beginning. We also know that the path traveled over must be continuous—that is, can have no gap. For a gap would mean that the particle was *nowhere* at that instant, which is impossible.

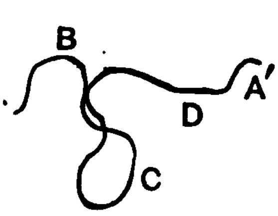

FIG. 2.

Think out some familiar examples of motion, and see how what you recognize as motion corresponds to the statements just given.

Note that the object is in motion only when continually changing position, and that position means merely distance and direction from any convenient object chosen for reference. Observe also that this reference object is selected without regard to whether it is itself in motion (as it always is) or not, but simply for convenience.

Watch a ball moving through the air. It is continuously changing distance and direction from some point on the ground. We do not in such a case stop to consider that the ground is a part of the earth which is whirling on its axis and around the sun. Suppose you are standing still on a car which is moving slowly forward. This means that the car is continuously changing its position relatively to the ground, but that you are not changing your position relatively to the car. You see at once that relatively to the ground you are in just the same motion as the car, at the same time that relatively to the car you are not moving. Thus, you are either in motion or not in motion, under precisely the same actual conditions, according to the object to which you refer the motion. Similarly, by referring your motion to a car ahead of you which is going faster, you say that you are losing on that car, meaning that relatively to it you are going backward. Hence—

Motion is purely relative, both in speed and direction. There is no such thing as absolute motion, because there is no fixed point in space (page 9).

Rest.—When a particle at a given instant is not in motion with reference to some point selected for convenience, the particle is said to be at rest. But at the same instant, with reference to some other point, the particle is in motion; thus, by properly choosing our reference point, the motion may be as fast as we please, and in any direction.

All that the term Rest really means is that *relatively to the chosen reference-point* the particle is not changing position at the given instant. When in every-day language we speak of an object at rest, we simply mean that it is not moving over the surface upon which it stands.

Rest, then, is not a condition different from motion. It is only the special case of motion where the body and reference point happen to have the same motion at the same time. Whenever, therefore, we make a statement about a body at rest, we must not think of it as re-

ferring to a body absolutely devoid of motion, or in a condition differing otherwise than in degree from that of a moving body.

The Direction of Motion of a particle at any given instant is the direction of its path at that instant. If the path is a straight line, its direction is, of course, that of the line. If the path is curved, its direction at any point is that of the *tangent to the curve* at that point (a line which touches but does not cut the curve).

Let A B C D E represent the path of a moving particle. Suppose the part C D of this path to be straight. When the particle is anywhere between C and D, its direction of motion is C D. At any point B of the path, draw a tangent F G. Then the direction of motion of the particle at B is that of the line F B G. Though the direction of the particle is continually changing as it passes B, we still say that its direction at the instant when it is at B is F G, and this is true in the same sense that in geometry the tangent is said to represent the direction of the curve at the point of tangency.

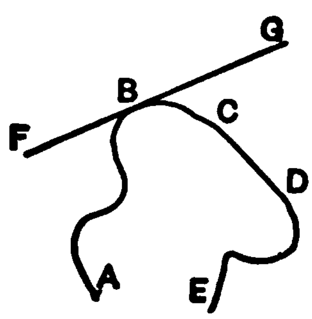

FIG. 3.

The path in Fig. 3 appears to be all in the plane of the paper, but it is meant to represent any very crooked path not in one plane. Bend a piece of wire, and study out the direction of motion of your pencil-point as you move it along the wire.

The Terms Uniform and Constant will be frequently used. To some extent they are employed to represent the same idea, and are therefore used interchangeably; but there is a distinction to be observed between them. We speak of a thing or quality as being uniform, implying that it is the same, wherever we are dealing with it. Thus, we speak of a uniform surface, shape, color, motion. A quantity is said to be constant if it has the same amount or value whenever we meet it; for example, a constant height, a constant speed.

Thus *uniform* is used mainly with reference to things or qualities with respect to place, and *constant* with reference to quantities in respect to time.

QUESTIONS.—What is meant by a material particle? Why do we deal with a particle instead of a body in kinematics? Mention the subjects of kinematics. How do we state the direction of a line? Can we state the absolute direction

of a line? Why? When do two lines have the same direction? How can two particles not moving in the same line move in the same direction? How do we define the position of a point? Can we state the absolute position of a particle in space? Why?

Define motion. What do we mean by the path of a moving particle? Why must the path moved over by a material particle be continuous? Show how motion is purely relative. If we speak of a car as moving along its track, to what do we refer the motion? Does this affirm anything about the motion of the car relatively to any other object? Is a body at rest relatively to the ground in any different absolute condition with respect to the sun, for example, than a body which is moving over the ground? Are we, then, to think of rest as indicating anything whatever as to any absolute condition of the body? Is there any such thing as absolute rest or absolute motion? Are we, then, to think of starting a body from rest as any different from making it move faster when already in motion? What do we generally mean when we speak of a body as at rest? Why do we commonly refer motion or rest to the ground? If a particle is moving along a curved path, what is its direction at any given instant? What distinction is to be observed between the terms uniform and constant?

VELOCITY, OR RATE OF MOTION.

The Veloc'ity of a particle at a given instant is the rate at which it is moving at that instant. This is also called its Speed.

Constant Velocity, Uniform Motion.—If the motion of a particle is such that in equal intervals of time, however short, the lengths of path traversed by it are equal, the particle is said to be moving with a Constant Velocity or Uniform Motion. The motion may, of course, be over any path, either straight or curved, regular or irregular. As the spaces gone over are equal for equal time intervals, it follows that for two such intervals the distance gone over would be twice as great as for one; for three, three times as great, etc. In other words, when a particle moves with constant velocity, the distance gone over in any given time is proportional to that time.

For uniform motion, the velocity is expressed by stating the distance moved over in a unit of time. Thus, velocities would be stated as 7 miles an hour, 3 feet a second, 2 metres a second, large units being usually chosen for convenience for great velocities.

If we could measure the actual distance passed over by the particle in one second, this would evidently give its velocity directly. It is, however, seldom convenient to do so; but we know that the space gone over is proportional to the time occupied. Thus, if the particle moves over 3 metres in one second, it would in 0·01 second move over 0·01 of 3 metres or 0·03 metre. Conversely, if it moved over 0·03 metre in 0.01 second, we know that it would move over $\frac{0·03}{0·01} = 3$ metres in one second, and the same would be true, however small the fraction of a second. Hence we may say that for uniform motion the velocity is stated by the ratio of the distance traveled to the time occupied. In the example just given the velocity would be $\frac{0·03}{0·01} = 3$ metres a second. The same velocity would have been found if we had measured the space traveled in a millionth of a second or in a year. Thus, we can find the velocity, even if the particle does not continue to move for a unit of time, but only for a very small fraction of a second, or even if the velocity is continually changing.

If a particle is moving with a uniform velocity of 7 feet a second, it will in 3 seconds pass over $7 \times 3 = 21$ feet; in 0·5 second, over $7 \times 0·5 = 3·5$ feet, and so on. In general, if V represents the velocity and t the time during which the body moves, the space S, or distance gone over along the path, will be

$$S = Vt.$$

From this it follows that for uniform motion the velocity V (per unit of time) is equal to the space S traversed in a given time t divided by that time—that is,

$$V = \frac{S}{t}.$$

And similarly the time t required to travel a given space S with a velocity V is found by dividing the space by the velocity—that is,

$$t = \frac{S}{V}.$$

Average Velocity.—If a particle moves with a changing velocity (as, for instance, a railroad train does, going now faster, now slower, stopping, and starting again), we may find it convenient to speak of its average velocity. This could be found if we knew its actual velocity at each instant, and then averaged all these velocities. The average

velocity, V, however, is also given by $\frac{S}{t}$, since the train would travel over the same total space S in the same time t, with its actual changing velocity, as it would with a uniform velocity.

Acceleration is continual change of velocity. If the velocity of a particle is increasing, the acceleration is called positive, or $+$; if the velocity is diminishing, minus, or $-$. For convenience, negative acceleration is generally called *retardation*, and acceleration is in that case understood to mean positive acceleration. In what follows, the term acceleration should be understood to include both positive and negative, unless otherwise specified.

Thus, if a moving particle in successive equal intervals of time, however short, passes over unequal distances, its motion and velocity are no longer uniform, but are accelerated. If the spaces passed over in successive equal intervals of time are greater and greater, the velocity is increasing, and the particle is receiving positive acceleration; if they are less and less, the particle is receiving negative acceleration, or retardation. Acceleration, like position and velocity, and for the same reasons, is purely relative. There is no such thing as absolute acceleration.

It is very important to remember that, if the velocity of a particle is in the slightest degree changed, acceleration must have occurred during the change; also, that if a particle has been "set in motion," it has been accelerated. The rate at which the velocity of the particle is being changed is known as the Rate of Acceleration. It is usually spoken of as acceleration only.

Constant Acceleration. — Uniformly Accelerated Motion.—If a particle is moving along any path in such a manner that its velocity is increased (or diminished) by equal amounts in equal times, the acceleration (or retardation) is *constant*, and the motion is said to be *uniformly accelerated*

(or retarded). If the amounts are unequal, the acceleration and motion are variable.

We have a multitude of examples in nature of accelerated motion and a few important ones of constant acceleration. Any heavy body allowed to fall freely toward the earth moves with a uniformly accelerated motion. Its velocity increases at the rate of 9·8 metres, or 32·2 feet, a second.

Laws of Uniformly Accelerated Motion.—Let a denote the rate of acceleration—that is, the increase of velocity a second. Then, if the particle starts from a state of rest, its velocity at the end of one second will be a units, at the end of two seconds $2a$ units, and so on. If t = the time in seconds after starting, the velocity v at the end of this time t will be

$$v = at.$$

This law may be expressed as follows: The velocity at the end of a time t, due to the acceleration, will be equal to the product of the rate of acceleration and the time.

For example, an object falling freely toward the earth has an acceleration $a = 32{\cdot}2$ feet a second. Its velocity at the end of 3·5 seconds would then be $v = 32{\cdot}2 \times 3{\cdot}5 = 112{\cdot}7$ feet a second.

The law as to the space traveled by a uniformly accelerated particle may be thus stated: The space s traveled in a time t is equal to one half the product of the rate of acceleration and the square of the time, or $s = \frac{1}{2}at^2$.

It has just been shown that the velocity at the end of the time t will be $v = at$. The velocity has been increasing from zero at a uniform rate; hence the *average velocity* is $\frac{1}{2}at$. If the particle had moved uniformly with this average velocity for the same time t, it would have gone over a distance $\frac{1}{2}at \times t = \frac{1}{2}at^2$, and this would have been the same as that actually traveled under the accelerated motion.

Combined Uniform and Accelerated Motion.—Suppose a particle moving with a uniform velocity V, to receive an acceleration a in the same direction as V, what would be its velocity at the end of t seconds? The acceleration would of itself produce a velocity $v = at$ in that time.

This velocity would be added to the other if the acceleration were in the direction of the uniform motion, and the actual velocity v' would then be $V + v$; or

$$v' = V + at.$$

If the acceleration were in the opposite direction to the initial velocity, then the actual velocity v'' would be $V - v$, or

$$v'' = V - at.$$

The motion in the second case would be what is called retarded motion.

What would be the space traversed in the time t? Under the uniform motion alone, it would be Vt. Under the accelerated motion, it would be one half the product of the rate of acceleration and the square of the time. If the two motions were in the same direction, the space traversed would be the sum of these. If the motions were in opposite directions (retarded motion), the change in position would be the difference of the two.

QUESTIONS.—Define velocity. Describe constant velocity and uniform motion. How is the amount of constant velocity expressed? How is it measured? Deduce the formula for the space passed over in a time t with a constant velocity V. If a steamer moving uniformly goes fifty miles in four hours, what is its velocity? If it does not move uniformly, but stops several times, what is its average velocity? If a bullet were to start with a velocity of one thousand feet a second, how far would it go in three seconds, if it continued to move uniformly? How long would it take to go a mile?

Define acceleration. Distinguish between acceleration and retardation. Can absolute acceleration be determined? Why? Does accelerating a body which is at rest differ in any way from accelerating one which is already in motion? If a body is "started" or "set in motion" from rest, is it accelerated in so doing? Describe constant acceleration. Does retardation differ in nature from acceleration? Deduce the formula for uniformly accelerated motion; for combined uniform and accelerated motion.

COMPOSITION OF MOTIONS.

Illustration of Composition.—Suppose that you are sitting at A, Fig. 4, in a car moving uniformly along, and that you are holding still in your hand a ball. The ball then possesses the same onward velocity as the car relatively to the earth, but is at rest relatively to the car. Roll the ball straight across the car to a person sitting directly opposite to you, at C. To do so you would, of course, aim it and roll it just as you would if the car were stationary. You

know from experience that it will go across in exactly the same way in either case, or, in other words, that its motion across the car is independent of the motion of the car itself so long as the car is moving uniformly.

The motion of the ball, then, relatively to the car, is in a straight line at right angles to the length of the car. If the car is moving, then the ball possesses two motions, that *across* the car and that *of* the car. We will assume both to be with constant (but not necessarily the same) velocity. What, then, will be the actual motion of the ball relatively to the ground or track, as, for instance, you might see it if you were standing in the street?

If you think carefully you will see that it will move along a diagonal line such as A C′; for, while rolling toward the opposite side C of the car, the ball and car are moving onward, so that C is approaching C′. When the ball has reached the opposite point of the car, that point will have arrived at C′. Hence the ball must have been traveling actually over the diagonal line A C′.

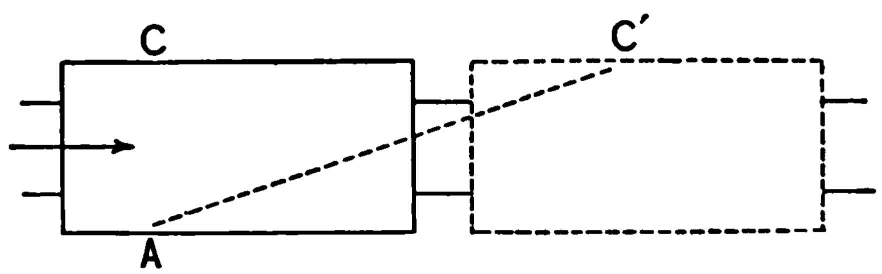

FIG. 4.—COMPOSITION OF MOTION.

This is a single example of a multitude of such combinations of different motions which are continually occurring about us at every instant. It is essential to see how we may study out such cases. We will take this up, then, as a study of pure motion.

Resultant of Two Uniform Motions.—Suppose a free particle to be moving with a uniform velocity along a straight line A B C, and at any moment, as when it is at B, another motion to be imparted to it which, if the first motion did not exist, would give it a uniform velocity in the direction B D. What will be the resulting actual motion? It is found from all experience that the particle will in any given time have moved just as far away from the line A C as it would have moved along B D if the first motion had not ex-

isted. The actual position of the particle will not be along either B D or B C; but it will have moved as far from the line B D as if only the first motion had existed, and as far from the line B C as if only the second motion had existed.

To state the case a little more completely, we must remember that any two lines have the same direction when they are parallel. Then, at any given instant after leaving B with both motions, say when it has reached *e*, the change of position of the particle, measured in the direction of B C, will be *d e*, and in the direction of B D will be *c e*. The actual motion of the body, relatively to any point fixed on A C, is neither along A C nor B D, but along some line which is found by experiment, and which will presently be shown to be the straight line joining B with *e*. The actual motion is called the *resultant motion*, and the actual velocity the *resultant velocity*.

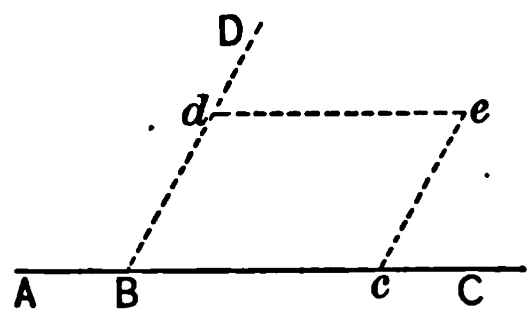

FIG. 5.—RESULTANT MOTION.

If, then, a particle be simultaneously affected by two or more motions, the amount of change of position produced in a given time by each motion, measured in its own direction, is as great as if no other motion were present.

The process of combining motions is called Composition of Motions, and will now be described.

Parallelogram of Motions.—Suppose a particle at A, Fig. 6, to be given simultaneously two such uniform motions in straight lines that in equal times the motions acting separately would bring the particle to B and to C. If they act together, the first would change the position of the particle by a distance equal to A B, measured parallel to A B and from the line A C; the second would change the position by an amount equal to A C, parallel to it, and measured from A B. Draw the lines C D and B D, parallel to A B and A C respectively. This will complete the parallelogram A B D C. Then D will be the actual position of the particle at the end of the time.

Subdivide the line A B into any number of equal parts at E, F, G, etc., and the line A C into an equal number at H, I, J, etc. Then, as the motion is uniform, the spaces A E, E F, F G, G B, A H, H I, etc., will be passed over in equal times. Hence, at the end of the first of these intervals, the particle must be at K, formed by completing the parallelogram A E K H. At the end of the second, the particle must be at L, similarly formed, etc. Hence, the particle in its actual motion must pass along the line A D, the diagonal of the parallelogram.

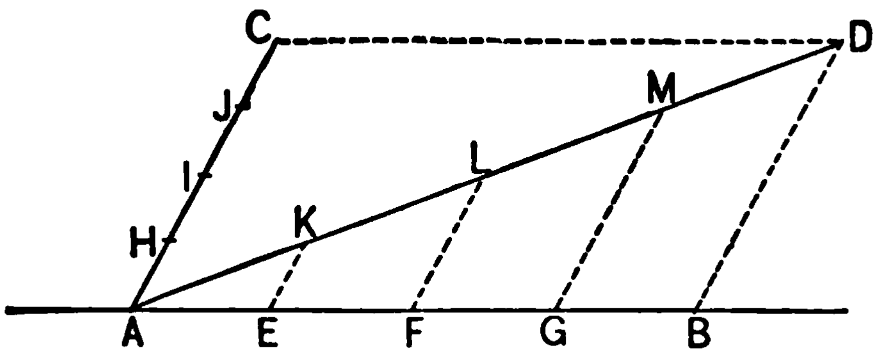

FIG 6.—PARALLELOGRAM OF MOTIONS.

If a particle be simultaneously given two uniform motions, we may find the resultant motion as follows: Draw through a point lines parallel to the direction of the two separate motions. Lay off on these lines lengths proportional to the spaces over which the particle would move in equal times. Complete the parallelogram and draw the diagonal from the starting-point. The particle would then move along this diagonal at a uniform rate, and in the same time that it would move over either side. The diagonal is then said to represent the resultant motion in direction and amount.

A person rowing a boat across a stream flowing with a rapid current, and heading always at right angles to the shore, will reach the farther bank far below the point opposite to which he started. The resultant motion will be diagonally across the stream, being compounded of the forward motion of the boat and the downward motion of the stream, which carries the boat with it. Similarly, a sail-boat with a side-wind does not reach the point it heads for, because the boat drifts sidewise with the wind, besides moving forward. This sidewise motion is called *leeway*. The resultant motion is therefore diagonal, and not straight ahead. In both cases, allowance for leeway has to be made by pointing the boat, if possible, enough farther up-stream, or into the wind, to cause the resultant motion to have the direction in which it is desired to move the boat.

Resultant of Several Uniform Motions.—If a particle be simultaneously given more than two uniform motions in the same plane, we may find the resultant of them all by first combining any two; then their resultant with a third; etc.

Let *a b*, *a c*, *a d*, *a e* represent in amount and direction the separate motions. From any point A draw A B equal and parallel to *a b*; B C

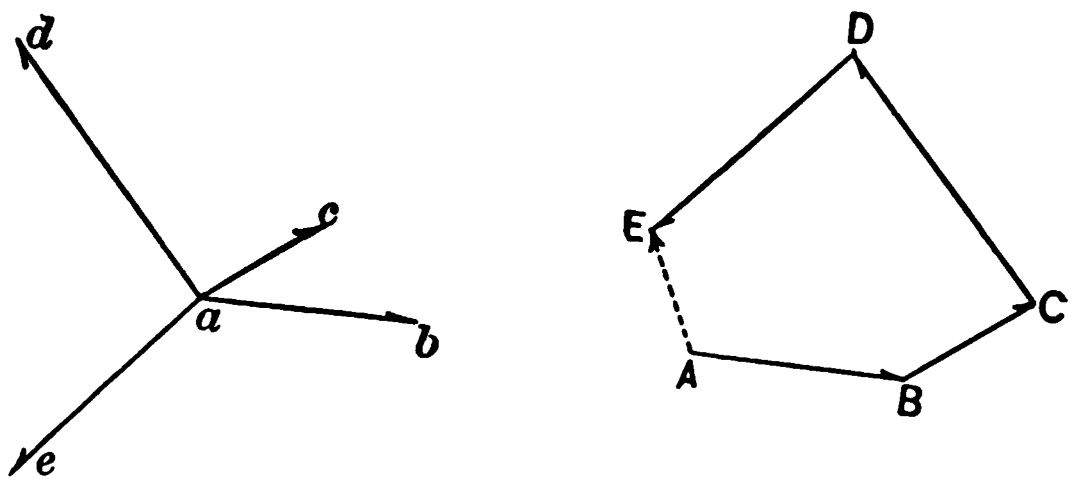

FIG. 7.—RESULTANT OF A NUMBER OF UNIFORM MOTIONS.

equal and parallel to *a c*; C D, to *a d*; and D E, to *a e*. Then the resultant motion would be uniform along the straight line from A to E.

Representation of Velocities by Diagrams.—Suppose that we wish to indicate by a diagram that a body is moving in a straight line with a uniform velocity of 15 feet a second.

Through any convenient point A on the paper, a line should be drawn in any convenient direction A C. At a distance of 15 units from A (fifteen eighths of an inch), a point B should be marked off. If a second motion is to be represented, another line A D should be drawn, making the same angle with A C that the direction of the second motion made with the first. Along this should be laid off in the same units a number to represent the second velocity; for instance, if this is 11 feet a second, a point E should be marked off, so that A E equals eleven eighths of an inch. It is clear, therefore, that A B and A E can be laid off to represent velocities—i. e., rates of motion or motions per units of time—as well as motions merely.

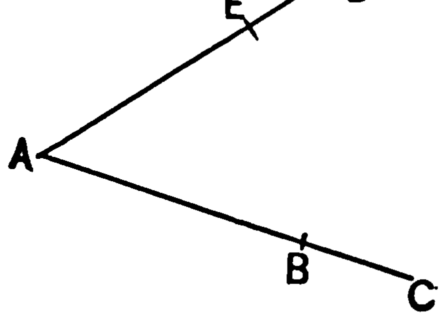

FIG. 8.

Composition of Uniform Velocities.—It has been shown how velocities can be represented by lines and diagrams just as mere motion is represented, the only difference being that a unit along the line stands for velocity—i. e., *feet per second* or *metres per second*—instead of mere change of position—i. e., *feet* or *metres.* All the foregoing statements as to the composition of motion apply, therefore, to the composition of uniform velocities.

Composition of Uniform Accelerations.—If we make the direction of the lines such as to represent the direction of the acceleration and the lengths of the lines proportional to the rate of acceleration, then the resultant acceleration will be found precisely as the resultant velocities or motions are found.

Resolution of Uniform Motions. — Two Components.—Suppose that a particle at A moves uniformly in the direction A B, reaching B in a certain time; and suppose, further, that we do not know anything about the cause of the motion. Then this motion may have been produced by the combination of several motions simultaneously impressed upon the particle.

Let us draw any two straight lines, N and P, at random, and ask whether motions in the direction of these lines could, if of the proper amounts, have caused the motion over A B.

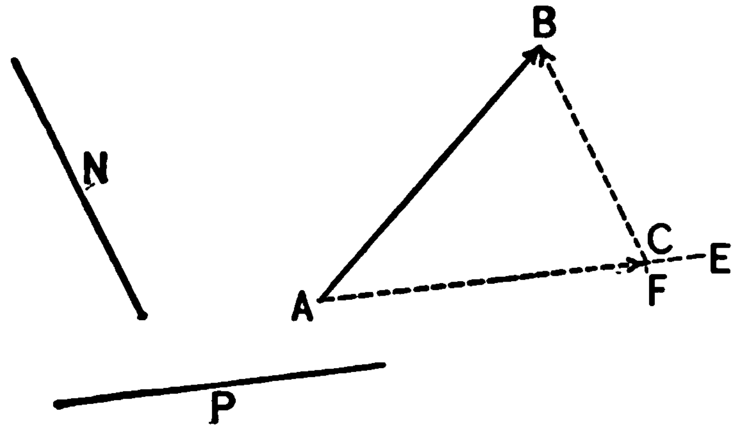

Fig. 9.—Resolution.

Through either A or B, draw a line parallel either to N or P, say A E parallel to P. Through B draw another line parallel to N. These two lines intersect at C. From the composition of motions, page 24, you know that a particle at A, simultaneously given the motions A C and C B, would move over A B. Hence, you know that a motion A C in the direction of P, combined with another, C B, in the direction of N, will produce the given mo-

tion. This process is called the *resolution into components;* that is. resolving the motion into component motions.

It is important to remember that the motion is always understood to take place in the direction indicated by the order in which the letters denoting the line are written. Thus, motion along A B would mean from A toward B; along B A, from B toward A.

Several Components.—By methods based upon those for the composition of several motions, it is possible also to resolve a given motion into any desired number of components in any desired directions.

A motion may be regarded as being made up of the simultaneous motions obtained by this process of resolution, for it is in every way precisely the same as if it were so made up.

QUESTIONS.—Draw on the blackboard a diagram representing the path of a ball rolled across a moving car. Explain fully why the ball takes such a course. What do you mean by resultant motion? Illustrate by diagram. Define resultant velocity. What is Composition of Motions? Describe and apply the parallelogram of motions. Illustrate in the case of a boat crossing a rapid stream or a sail-boat running across the wind. How can you find the resultant of several motions? What is meant by resolution of motions? Illustrate by figure. What is possible where there are several components?

MISCELLANEOUS QUESTIONS AND PROBLEMS.

If a train of cars is moving uniformly at a rate of 20 miles an hour, how far will it go in 5 hours? In 3 days? How long will it take the train to go 1,000 miles? If it traveled 520 miles in 20 hours, moving uniformly, what was its velocity?

Wild pigeons have been shot in the latitude of Albany, N. Y., with Carolina rice undigested in their crops. About what must have been the velocity of their flight? (Apply scale to your map of the United States.)

If a train goes from Boston to Albany in 6 hours and the distance is 200 miles, what is its average velocity?

A particle starting from rest and given a uniform acceleration of 50 feet a second would have what velocity at the end of 20 seconds? $V = 50 \times 20$. What distance would it traverse in this time? *Ans.* 10,000 feet.

A particle starting from rest and moving with uniformly accelerated motion is found to have a velocity of 100 feet a second at the end of 5 seconds. What was its rate of acceleration? $a = \frac{v}{t} = \frac{100}{5.}$ If the same particle had been found to have traveled 90 feet in 3 seconds, what would have been its acceleration? $a = \frac{2s}{t^2.}$ What time would the particle have taken to travel 160 feet with this acceleration? *Ans.* 4 seconds.

If a particle moving with a uniform velocity of 500 feet a second were to be given an acceleration of 50 feet a second in the direction of its motion, what would be the velocity at the end of 20 seconds? $v' = 500 + (50 \times 20)$.

If the same acceleration were imparted in the opposite direction, what would be the velocity at the end of 3 seconds? $v'' = 500 - (50 \times 3)$. What at the end of 10 seconds? $v'' = 500 - (50 \times 10) = 0$—i. e., it would have been brought exactly to rest. What at the end of 20 seconds? $v'' = 500 - (50 \times 20) = -500$—i. e., the particle would be moving in the opposite direction from that at the outset.

What would be the distance traversed in the first example? *Ans.* 20,000 feet. What in the second?

Uniform velocities of 10 feet per second northward and 5 feet per second eastward are simultaneously given to a particle. Draw a diagram by the parallelogram of velocities, which will show the relative direction and magnitude of the resultant velocity.

ENERGY.

NATURE OF ENERGY.

Work and Energy defined.—There are two fundamental terms—energy and work—which are used in physics in very nearly the same sense as in every-day speech. In arriving at their scientific meaning, we shall begin by considering the ideas which they commonly represent to us.

When we say that a man has much energy, we mean that he has much capacity for doing work. By this we may imply bodily work or mental work, or both; but in our present study we are not concerned with mental phenomena or exercise of the will, so we need think only of the man's muscular energy and of the work which he can do with his body.

In physics, when we say that an inanimate object or portion of matter has energy, we mean that it possesses capacity to perform physical work.* Thus—

Energy is capacity for doing Work.

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* Energy is often spoken of as the *power* of doing work, or simply as *power*. The term power, however, has a special meaning assigned to it in physics, and should not be used in this connection. (See page 101.)

It will be found as we go on that there is reason to believe that whenever a body (that is, a portion of matter large or small) performs work, it does so by accelerating the motion of other portions of matter. In many cases, this acceleration is visible; in others, it is shown only by close study; in others again, it is only supposed (with more or less probability) to be the fact.

By way of illustration of the first class of cases, find some heavy object which will roll easily—a large wooden ball, a cannon-ball—anything that will move with little friction. Select a smooth, level surface on which you can roll it. The more massive the object and the smoother the surface, the more convincing the experiment will be.

Let us take a heavy ball on a smooth floor. Begin with the ball at rest; then with it in motion. Accelerate it by pushing it. In order to do so, you will have to exert muscular effort in a manner which you will recognize as what is familiarly called "doing work." Repeat the experiment in a variety of ways. You will invariably find that to accelerate the ball you must perform work upon it. This is a universal principle.

It is found also to be true that the amount of work done to produce a given acceleration in a given object is the same at whatever velocity the particle is already moving; for instance, to accelerate its motion by 10 feet a second would require no more work if the object is moving a mile a second than if its velocity is only a foot a second, or if at the outset it was zero.*

Take another familiar example. Throw a ball horizontally. All the time the ball is in your hand you are pushing it forward by the hand and continually accelerating it. You will recognize by your feel-

* The student will find the whole subject much clearer and more interesting if he will try for himself the experiments suggested. The teacher should see that this is done in every case where possible, and should encourage the pupils to describe in the class-room their own experiments. Learners will find it much easier to remember the subjects they study if they will talk them over among themselves at unoccupied times out of school, and plan to work together upon experiments at home. It is by no means necessary that the apparatus should be exactly that here described. The spirit and habit thus acquired of trying things for one's self and of taking nothing for granted that can be tested by experiment, will be of untold value through life; while the ingenuity developed in constructing apparatus, in using tools, and especially in adapting things at hand to the purposes desired, must prove a most desirable acquisition.

ing, especially if you continue throwing the ball for a few minutes, that you are doing work during each throw.

In each experiment you should be able to discover that you are doing work so long and only so long as you are increasing the velocity of the object—i. e., producing acceleration.

If the ball had been set in motion by some inanimate material body, that body would have accomplished the same result as you. It would, therefore, have performed work.

A body is performing work whenever, and as long as, it is causing acceleration of any other portion of matter. When a body A is accelerating another body B, we say that work is being done *by* A and *upon* B.

Inertia.—As the result of all sorts of experiments upon all kinds of material objects, it appears that no particle of matter of itself is capable of changing in the slightest degree either the direction or velocity of its motion. This is briefly expressed by saying that *matter is perfectly inert.* By this we do not mean that a given particle is not in motion, but simply that it has no capacity of itself to change its rate or direction of motion—that is, if it is moving relatively to its surroundings it can not of itself change its direction or speed, or if it is at rest relatively to them it can not of itself start into motion.

From this statement and the foregoing experiments, it follows that a material particle can be accelerated only by the performance of work upon it by some other object. To be able to do work, this other object must possess energy.

Whenever, then, a particle of matter is being accelerated, work is being done upon it by some other portion of matter possessing energy.* This fact is of the utmost importance to any clear comprehension of the laws of Physics.

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* The above is not true in a general sense of a *body* of matter, for the individual particles always possess some energy relatively to one another which may act (in the case of a heated body) in such a way as to change the direction and velocity of the body by expanding it, or otherwise. The statement is true, however, of any body as a whole so long as it retains its size and form.

Three statements, called the three LAWS OF MOTION, were given two centuries ago by Sir Isaac Newton in his classic work, the Principia. They stand to-day without change as presenting the current ideas on the same subjects. The first law, virtually a statement of this property of matter, is as follows:

"Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it may be compelled by impressed forces to change that state."

Just what is meant by *force*, you will learn later. For the present it will be sufficient if you understand the phrase "by impressed forces" to mean by the action of some other matter possessing energy.

Free Motion.—A body is said to be free to move in a given direction when there is no resistance opposing its motion in that direction. In its widest sense, a *free body* is one whose motion is unresisted in all directions, and the motion of such a body would be free motion in the broadest sense of the term. A smooth round ball rolling on a truly horizontal smooth surface is nearly free to move in any direction over the surface.

Nature of Energy.—A man is able to perform work because he possesses muscular energy. We shall not attempt to consider in what that form of energy consists, but we must ascertain what is the condition of an inanimate object when it possesses energy. In doing so we shall find that *matter can possess energy only by being in motion.*

Let us first examine the energy of an object in visible motion. Take two balls, A and B, of about the same size and of any elastic ma-

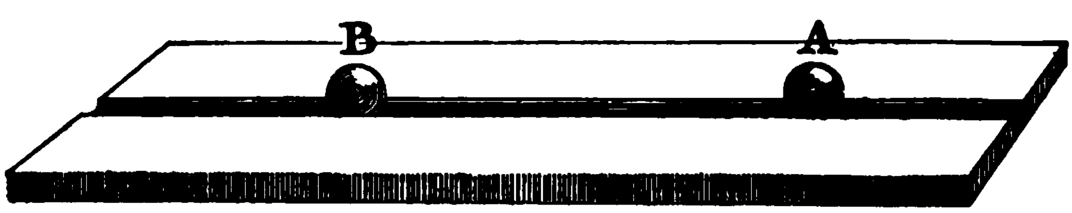

FIG. 10.—EXPERIMENT WITH BALLS ON GROOVED BOARD.

terial. Ivory or glass balls are the best, but marbles or croquet or tennis balls will answer. Place them on a wide straight crack in the floor or table or on a grooved board, or lay down a couple of planed boards with edges a little apart to serve as guides. The result of the

experiment will be more marked if the end of the board toward A is raised very slightly, nearly but not quite enough to have the balls keep in motion of themselves, thus overcoming friction.

Start A rolling toward B. When it strikes, B will be accelerated—i. e., if at rest it will be set in motion; if moving in the same direction as A, it will be made to move faster; if moving (not too fast) toward A, it will be stopped and set in motion in the reverse direction. All these are merely cases of acceleration of B by A.

Place A and B in contact, but both at rest. Neither can accelerate the other. Let A and B roll down the board in actual contact, with the same velocity. Again, neither can accelerate the other.

You see, then, that A (possessing energy imparted by you) can accelerate B when it has a velocity relatively to B, and can not accelerate B when it has no velocity relatively to it; but, to accelerate B, requires that work should be performed upon it. Hence A must have possessed energy relatively to B when it had a velocity, and none when it had no velocity relatively to B. Again, note what the condition of A is after it has done work upon B. Its velocity is much reduced, and may be even zero. A loss of velocity has accompanied the performance of work, and was therefore apparently necessary to it.

If B is moving toward A at a certain speed, A may not have sufficient energy to send it backward, but will merely stop it or perhaps only lessen its speed. In this case A will bound back, and the work will therefore have been done by B upon A, as A will have been accelerated while B will have lost velocity.

In the first experiment above, the acceleration of B appears to be instantaneous, but in reality the balls are in contact for a time which is reasonable. although so short that we do not easily perceive it. During this time, the velocity of A is diminishing and that of B is increasing.

Motion necessary to Energy.—From a multitude of experiments of this sort, the conclusion is drawn that a body in visible motion possesses energy *because of its motion.*

Increase of Energy with Velocity.—Roll A with different velocities. The faster it moves, the faster B will move after the blow. To make B move faster requires, as you know from your former experiment in rolling the ball, more work to be done upon it. Hence the greater the velocity of A, the more work it can do, and therefore the more

energy it possesses. The less the velocity of A, the less its energy. If its velocity is zero, its energy is zero. Therefore, the energy of a body in visible motion *increases with an increase of its velocity.*

From general experience with all forms of energy, the hypothesis is reached that, just as the energy which we have been dealing with in the moving balls was due to the visible motion of their mass, so *all energy of whatever form is due to motion of matter.* The motion and even the moving portions of matter may, however, be invisible, owing either to smallness, to the peculiar character of the matter, or to other causes.

It is also found, as will be shown, that the amount of energy depends on the amount (mass) of moving matter as well as on its velocity. The property of inertia further indicates to us that energy is a capacity acquired by matter and not inherent in it. Hence it is assumed that—

ENERGY, OR THE CAPACITY OF DOING WORK, IS POSSESSED BY MATTER IN VIRTUE OF ITS MASS AND VELOCITY.

When we speak of a body, then, as possessing energy, we mean that the matter of the body is in motion, either visible or invisible. In other words, we mean that the body itself contains the energy. In contrast to this you will see, as you go on, abundant instances where bodies are performing work (as where a weight runs a clock), but where the energy is *not possessed by* the body but only *transmitted through* it. In such a case the energy is imparted to the body by the source of energy, and given up by the body to the thing worked upon.

Inasmuch as it is often convenient to use a term which suggests the idea of motion when energy is referred to, the adjective kinet′ic is sometimes prefixed to the word.

QUESTIONS.—What do we mean when we say a man possesses energy? Give the ordinary meaning of the term energy; the definition of energy as used in physical science. What do we mean in physics by the term body? What is believed always to occur when work is done? Is this known always to occur? Why not? If you accelerate a rolling ball by pushing it with your hand, how do you recognize that you are doing work? Can matter be accelerated in any way except by doing work upon it? If a ball is at rest upon the floor and you set it in motion so that its velocity is one foot a second, is the work done by you any greater or any less than if the ball had been moving with a velocity of 5 feet a second and you had increased it to 6 feet? How would you explain this from the statements concerning rest as given under Kinematics? If the ball is rolling without friction at a uniform speed, do you have to do work to keep up that speed?

When do we say that an inanimate body is performing work? When do we say that a body is having work done upon it? Is any particle of matter capable of starting itself into motion? Of stopping itself? Of changing its velocity in any way? Of changing the direction of its motion? Of accelerating or retarding itself? What term do we use to express the inability of matter to do these things? Does Inertia mean anything else? Suppose a bullet is moving 2,000 feet a second, is it inert? Suppose that the same bullet is lying motionless on the floor, is it any more or less inert than when moving? By declaring a body to be inert, do we thereby declare anything respecting its motion?

State Newton's first law of motion. What is meant by free motion? By a free body? How is it found that matter can possess energy? Can it possess energy in any other way? What does the experiment with the rolling balls show as to the velocity of A with respect to B in order that A should be capable of doing work upon B? How does this illustrate that a body in visible motion possesses energy? How that it possesses energy because of its velocity? If the velocity is greater, is the energy greater or less? Prove this by experiment. Give the fundamental general hypothesis respecting the nature of energy. Is this based on experimental knowledge, or is it purely a matter of belief? What do we mean by saying that a body "possesses" energy? Is the motion to which energy is due always visible? Is energy due to anything except velocity? Is energy the same as velocity? Could an imaginary moving point possess energy? Can a body transmit energy which it does not possess? Give an illustration. What is meant by kinetic energy? What is the meaning of the adjective kinetic? Is all energy kinetic?

FORMS OF ENERGY.

The Kind of Motion, in virtue of which a body possesses energy, makes a difference in the sensations which that energy excites in us, as well as a difference in the effects which it produces when doing work upon other bodies. For this reason, energy is said to exist in various *forms.*

Examples of Forms of Energy.—Of the different kinds of motion, there is, first, visible motion of the body as a whole, moving along through space; this gives rise to energy of visible onward motion. A body may rotate or spin like a wheel or top, and its energy is then in the form of visible energy of rotation. It may not be in visible motion at all, but possess only invisible motion of its particles or molecules; its energy is then in the form which is called heat, sound, radiant energy, according to the precise character of the molecular motion. Finally, energy may be in the form exhibited by electrical currents, etc.

These varied forms will be considered in detail in the chapters on Sound, Heat, Light, Electricity, and Magnetism. A few examples, however, will be here given in some detail, as it is of the utmost importance to any real knowledge of physics to obtain clear ideas of energy.

Energy of Visible Onward Motion.—To prove that a body possesses energy (actual, kinetic) with reference to a given point, we have only to show that its velocity with reference to this point is greater than zero. As motion is purely relative, we must remember that the velocity, and therefore the energy, will be different in amount according to the point to which they are referred, for the velocity referred to one point may be large, to another small.

Two cannon-balls fired at the same instant, in the same direction and with the same velocity, would have immense energy referred to the cannon they had left, or to the ground they were moving over, or to the target at which they were aimed. But relatively to each other they would possess no energy at all, because their relative velocity is zero, just as two parts of the same ball would have no energy with reference to each other.

A railroad train in motion over the track possesses energy with respect to any object stationary upon the track, or moving more slowly than itself. Witness the destruction produced if the train runs into another which is standing still, or even moving slowly ahead of it. If another train be approaching the first, then the velocity of the two trains relatively to each other is, of course, the sum of their separate velocities relative to the track. Their energy relative to each other is therefore much greater than their energy relative to a stationary train; while if there are two trains moving in the same direction with the same velocity, they possess no energy relatively to each other, although both have great energy relative to the track and earth.

A stone lying upon the ground possesses no energy relative to the ground, but think of the velocity with which the stone is moving, together with the ground beneath it, as the earth spins on its axis once each day, and whirls along on its path around the sun; and imagine the immense energy it possesses relative to a point not so moving.

Energy of Visible Vibration.—Suspend a stone or any heavy object by a string. The stone will hang straight

downward. Pull it aside a few inches in a horizontal direction, and let it go. It will swing to and fro. Notice that, when you release it, it begins to move slowly at first, then more and more rapidly, till it reaches the lowest point of its swing, and then it moves more and more slowly as it rises to the other end of the sweep. There it stops and then begins its return swing. Notice also that it always takes, as nearly as you can tell, just the same time for each swing made. A body suspended and swinging in this way is called a pendulum, and the to-and-fro motion of the stone or "bob of the pendulum" is pendular motion, or *vibration.*

Examine now the energy of the stone. You will see that the instant you release it, and before it starts, it has no velocity, and therefore no energy. As it moves it gradually gains energy, for its motion is accelerated until it reaches the lowest point. Then it begins to lose velocity, and therefore energy, moving with retarded motion, and so continues until it reaches its turning-point, where for an instant its velocity is zero, and it therefore possesses no energy. The same series of changes is gone through with at each swing. The energy of a body vibrating in this way is called *energy of vibration*, or *vibratory energy.*

Place a rubber band over the tips of your thumb and forefinger, and keep it stretched by drawing them apart. With the other hand pluck the band near the middle. This will set it in vibration, and it will give out a musical note. The string of any musical instrument will show the same thing. Examine the vibrating side, and you will see that it is in to-and-fro motion. Touch a bit of paper against it, and a buzzing sound will be heard as the band repeatedly strikes the paper. Each particle of the band is moving with a motion very similar in character to that of the pendulum. Now, the band is a material substance, and you have found that it is in motion. It therefore possesses energy. We refer the motion and energy to the position of the band when at rest.

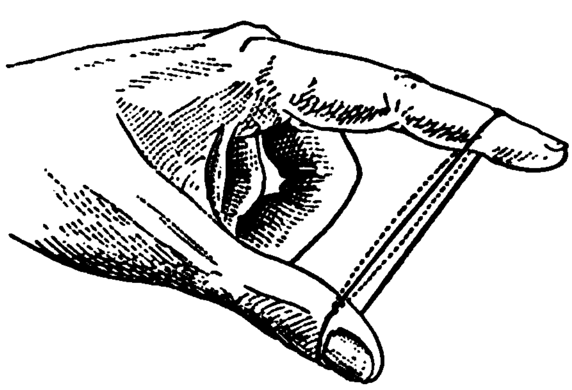

FIG. 11.—VIBRATING BAND.

Sound Vibration.—When the band is vibrating, a sound is heard. This sound comes to your ears through the

air. The vibrating string imparts its energy to the air, setting the air particles into a similar to-and-fro (pendular) vibration. Pulsations are thus begun in the air which travel off from the band in all directions, much as waves of water travel when a pebble is dropped into a pool. Some of these pulsations reach the ear and cause there the sensation of sound. The particles of air are matter. They are in to-and-fro motion when conveying sound. They therefore possess energy just as does the vibrating string itself, and this energy we call the energy of sound vibrations.

Sound vibration is thus energy of motion, but the motion, unlike that of the pendulum, for instance, is *invisible*, and it excites in us a sensation (sound) which the pendulum does not. It is therefore called another form of energy.

Heat.—In a body conveying or giving out sound, the molecules are vibrating in a very regular and systematic manner, all the molecules at any given point of the body swinging to and fro together in nearly the same direction and at nearly the same rate. The regularity may be compared to that of the steps of a body of soldiers marching in correct time.

But the molecules of all bodies possess, whether in sound vibration or not, another and entirely distinct motion. They are never without some of this motion; no body has been ever known to be reduced to a condition where it was absent. This motion differs from that of sound vibration in being irregular and unsystematic, when we consider the movement of the individual particles. The molecules are flying to and fro, first in one direction, then in another, no two at once in the same direction, now fast, now slowly, jostling against their neighbors and being jostled in turn. The irregularity of this motion may be compared to that of the footsteps of the individuals in a great crowd of people, no two of whom are trying to move in the same direction or at the same rate of speed. Each molecule at any given instant

has a definite velocity (relative to a fixed point upon the body or vessel holding it), and in virtue of its mass and this velocity it possesses energy.

Such energy is Heat. The more violently the particles are flying about, the hotter is the body. Now, you easily perceive that heat affects our senses in a manner entirely different from sound, or from the energy of an onward moving body. Hence, heat is another form of energy.

Radiant Energy.—Light.—We have reason to believe that all bodies are surrounded by a kind of matter which possesses many properties quite different from those characterizing substances with which we are familiar. This matter is called the luminif'erous Ether, or simply the Ether. You will learn more about it when you come to study Light.

The molecules of bodies, as they leap about in performing the heat movements, stir up this ether at the points where it is in contact with them, and set its particles into pendular vibration. This motion is passed along in a wave in all directions from the hot body. Each particle of the ether must be supposed to possess mass, and, as it has also this motion, it must possess energy. Such energy is called Radiant Energy.

If radiant energy falls upon the skin, it may excite the sensation of warmth. If it is of the right rate of vibration, and falls upon the eye, it excites the sensation of light. It is by means of radiant energy that we are able to see. If it falls upon certain prepared "plates," it produces chemical effects which we make use of in taking photographs. It also stimulates the growth of plants; and, curiously enough, it has been recently proved that certain electrical effects are propagated through space by this same radiant energy.

Notice that of this form of energy we know hardly anything by direct observation. We are acquainted with its effects and its laws; but we do not even know that there is an ether in the same sense in which we know that air exists. We feel sure that there must be an ether, that it must be material, and that it must transmit energy, because we have various effects which we can explain by these suppositions without violating any of the better known laws of matter.

QUESTIONS.—What is meant by the term "form of energy"? What would be the form of energy possessed by a moving cannon-ball? By an avalanche? By an arrow in its flight? By the earth in its motion through space? By the earth in virtue of its rotation about its axis? Give other examples of this form. Do the cars of a train possess any energy of onward motion with reference to one another when moving steadily? If the forward car is suddenly checked by brakes, a collision, or by running off the track, do the cars behind possess any energy relatively to it? Two trains are moving with the same speed on the same track; if in the same direction, do they possess energy relatively to each other? If in opposite directions?

Show how the swinging pendulum possesses energy? What is this form called? At the extreme end of its swing, does the pendulum possess energy? What is supposed, then, to have become of the energy which is possessed by the moving pendulum? What is the kind of motion of a violin-string when giving out sound? What is the energy of this form called? Why do we call this a different form of energy? To what do we refer the energy and motion of a vibrating body?

How does the energy of sound vibration differ from that of the pendulum? Describe briefly this form of energy. Describe briefly the motion constituting heat-energy. That constituting radiant energy. What proof have we of the existence of an ether?

TRANSFORMATION AND CONSERVATION OF ENERGY.

Energy indestructible.—When the properties of matter are considered, it will be shown that matter is indestructible, or, in other words, that the quantity of matter in the universe appears to be constant. The same statement is true of energy, but of no other physical quantity. We have seen that energy may exist in several forms. It is also true that energy of any one form may be changed into energy of any other form, or, as we say, may be transformed. But, although it may be changed in form as much and as often as we please, and although such changes are going on without ceasing all around us, yet *no portion of energy is ever lost or destroyed.*

Whenever a given quantity of energy disappears at any place, an exactly equivalent amount appears somewhere at the same instant, either in the same or different forms. Thus, the *total quantity of energy in the universe appears to be constant.* This law is known as the principle of Conservation of Energy.

We must remember, then, that nothing but energy can be the cause of energy; and that, if energy disappears in a given place, an equivalent amount must somewhere be produced. We can change the place or form of energy, but we can neither create nor destroy it any more than we can create or destroy matter.

In familiar language we speak of energy as appearing or disappearing: as being generated, consumed, lost, etc. But this is allowable solely as a matter of convenience.

The Law of Conservation of Energy is wholly based upon experiment and measurement, as are all physical laws. We know of no exception to it. The confidence which physicists have in it is so great that it is used as a test to determine whether anything is or is not energy. If the thing in question can be changed into one or more known kinds of energy, or if any known kind of energy can be transformed into it, then it is believed to be energy.

Instances of Transformation of Energy and examples of various forms will now be given. Many more will come up incidentally as we go on. It is not possible at this stage of advancement for the pupil to measure the quantities of energy transformed; the mere fact of transformation alone will be shown:

Rub the fingers briskly to and fro upon any surface, say of cloth or wood, and you will feel a sensation of warmth, due, of course, to heat. You have expended muscular energy in moving the hand backward and forward against the resistance of friction, and heat has been produced. The more the muscular energy expended, the greater the amount of heat generated. The muscular energy is changed into the form of energy which we call heat (page 37).

Rub briskly over a cloth or wooden surface a smooth light piece of metal, such as a button or a thin key. It will soon become warm, and even quite hot to the touch. Here, again, muscular energy has been transformed into heat energy.

Place a lump of lead upon an anvil. Strike it a blow with a heavy hammer. The lump will be crushed out of shape, and you will find, on picking it up, that it is quite warm. At the instant before striking, the hammer, owing to its mass and velocity, possessed energy of onward motion imparted by the person and by gravity. On striking the

lead the hammer is brought nearly to rest, and therefore loses nearly all this energy. The equivalent of most of this energy appears in the form of heat in the lead. Here, then, energy of onward motion is converted into heat. Not all the energy is thus transformed, however, for part remains in the rebounding hammer, and part is transferred to the anvil, setting it into slight motion. The hammer and the anvil are also set into sound vibration, some of the energy being thus changed into that form of energy.

Availability of Energy.—When energy is transformed, it usually happens that not all the energy of the given form can be changed into the desired form, but that some part (usually a considerable part) is incidentally and unavoidably changed into other forms which are not desired and are of no use to us. This follows from certain laws of energy which can not be here considered, and which lead us to regard some forms of energy as of a higher grade than others.

The quantity of energy thus changed into forms not desired and not available for our purposes at the time, is often spoken of as wasted or lost; but you will see that it is still energy, and is only wasted or lost in the sense of *not being available* for the purpose in hand.

Examples of unavailable heat resulting from the expenditure of energy by man or by machines are of every-day occurrence and often occasion great inconvenience.

A saw used to cut wood or metal becomes warm or even hot; a drill or gimlet is heated as the hole is bored; a file "heats" when in operation on a piece of metal; a car-wheel grows hot when the brakes are applied. The saw and drill are sometimes oiled in order to reduce the friction and thus lessen the work done in turning them; the heat produced is, of course, diminished in the same proportion. A shaft, journal, or axle of any kind, if not properly oiled to reduce friction, would heat very much in its bearings, causing the destruction or injury of the bearing, or at least making it impossible to turn the shaft. Instances of this are to be seen in a "set" wagon-wheel and the "hot box" on the railroad train.

In all these cases the heat is a serious cause of inconvenience. It is here a kind of energy which is not wanted, and its production causes a waste of the energy of the operator or the machinery.

Potential Energy.—Bodies are frequently so situated with respect to some kind of energy—for example, that causing gravitation or electrical and magnetic effects—that if left free to move they will themselves acquire energy. In such instances, the body does not possess actual energy, but only the possibility of acquiring it. It is said to possess *potential* or *possible* energy.

Thus any object anywhere above the earth's surface, whether moving in any direction or at rest, is said to possess potential energy with reference to the surface. This, however, is not energy actually possessed by the object, but is merely a convenient phrase to denote the energy which the object can acquire by moving from its given position to the surface of the earth.

A piece of iron at a distance from a magnet possesses potential energy with reference to the magnet, because, if allowed to move, it will acquire actual energy in moving toward the magnet.

Work further defined.—In all these illustrations of the change of place or form of energy, the process of transference or of transformation is called Work. Thus, when A accelerates B (page 31), we say that A does work on B. When we rub the metal and produce heat (page 40), we do work; when the hammer strikes the piece of lead (page 40), it performs work upon the lead. Every such case has been shown to be merely a change in place or form of energy. We may therefore conclude that

Work is merely the process of changing the place or form of energy.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

What have you learned in regard to the indestructibility of matter? Explain fully what is meant by the transformation and conservation of energy. If energy disappears, what are we to infer? Are there exceptions to the Law of Conservation of Energy? Give instances of the transformation of energy, repeating those explained in the book, and drawing upon your own experience.

Show by illustrations that energy when transformed is not all available.

Explain and illustrate potential energy.

When the clapper strikes the bell, into what is its energy of onward motion transformed?

When a hot body is giving rise to vibrations in the ether, into what kind of energy is its heat-energy transformed ?

The steam-engine transforms what kind of energy into the energy of onward motion of the train ?

A cannon-ball, striking a target, becomes heated. Suppose all its energy of onward motion were converted into heat-energy, what would be the result ?

A bullet or cannon-ball striking a target or armor becomes heated. A large part of its energy is converted into heat-energy in itself and in the object penetrated and crushed. Suppose all its energy were to be converted into heat at the blow, how hot would the ball be ?

Meteorites, or shooting-stars, are masses of material which enter our atmosphere from space and fall by their weight toward the earth They enter with, or acquire, a very great velocity While moving through the air with this speed, they experience resistance, in overcoming which, heat is produced in sufficient amount to raise them to the red or white heat that renders them visible. What kinds of energy are here transformed, and how ?

Explain the meaning of the terms uniform motion, uniformly accelerated motion, retarded motion, and state again how such effects are produced.

If while a steam-launch is in motion the smoke rises vertically, what must be the direction of the wind ? What, its velocity ?

Imagine yourself on an observation-car traveling at a high rate of speed. If you should throw a ball vertically upward, what would be the appearance of its path to an observer not on the train ? Draw a diagram showing its actual path.

Account for the fact that it is as easy to pitch quoits on the deck of a rapidly moving ocean steamer as on land.

FORCE.

NATURE AND ACTION OF FORCE.—WEIGHT.

Tendency to Acceleration.—When the ball A of experiment on page 31 strikes B and accelerates it, the action is not instantaneous, but merely of very brief duration. Time is required to accelerate any mass of matter, however small. During this time of action, the velocity of B is gradually increased by the action of the energy of A; and we may say that, while the action is going on, B has a tendency to acceleration with respect to A. By this we mean that B will be accelerated, unless some resistance is offered.

In general then, if a body is said to have a *tendency to acceleration*, we imply that its motion will be accelerated

unless some resistance acts to prevent. It will therefore be understood that the tendency is spoken of as existing, whether the acceleration occurs or not.

It is clear in this case that the tendency to acceleration is due to the action of the energy of A upon B. As there is reason to believe that acceleration can never be produced by anything but energy, so tendency to acceleration must always be due to the action of energy.

In this experiment the duration of the contact between A and B, and therefore of the tendency to acceleration, was very brief. But we have many examples of continuous tendencies. For instance, any object tends to fall (with acceleration) toward the earth. This tendency is continuous. A piece of iron near a magnet tends continuously to approach the magnet.

Force.—This action by which some forms of energy sometimes produce in bodies a tendency to acceleration is called Force. We may then define force as being that action of energy by which it produces a tendency to acceleration. It is therefore merely an action of energy upon bodies.

Familiar Examples of Tendency to Acceleration, or Force.—Hold this book, or any object, in your hand, just above the table. Let go your hold. It falls downward until it reaches the table, or some other object which interrupts its motion. Here, then, is a tendency to acceleration — and thus, a force. This force we call Weight.

Tear off some bits of newspaper not larger than the letters of this book. Take your eraser, or, better, a piece of vulcanite, such as a hard rubber comb, or a fountain or stylographic pen. Rub it once slowly over your hand. Bring it just over the bits of paper. They do not move. Wipe the vulcanite dry, then rub it briskly for a few seconds upon any dry woolen, silk, or fur, and immediately bring it again over the bits. They fly up, and perhaps stick to it. Here is tendency to motion, or force, due to another cause, Electrification.

In many instances a sensation of push or pull enables us to recognize the presence of a force, as when we are holding an object in the hand. It may aid us if we think of force *as* a push or pull (due to energy of some kind), but we must not regard this as a definition of force.

Action of Force.—In speaking of acceleration or other effects, such as compression, bending, stretch, etc., we should speak of them as due to the action of energy, for only energy can produce them. But it is often more convenient to speak of them as due to the action of the force instead of to that of the energy which causes the force. A force, it will be seen, can have no capacity to do work; such capacity is energy. It is of very great importance that this fact should be borne in mind whenever work or anything else is spoken of as due to the action of force.

Line of Action of a Force.—The direction in which the body tends to be accelerated is called the direction of the force. The particular line along which a particle or body tends to be accelerated is called the line of action of the force.

Two or more Particles necessary to a Force.—We shall find, as we go on, that whenever any body or particle has a tendency to acceleration, we have reason to believe that there is somewhere another body or particle which tends to be accelerated toward or away from the first at the same time. The tendency to acceleration never belongs to a single body only, or to a single particle of matter, but is always a tendency of two or more bodies or particles to approach, or recede from, one another with an accelerated motion. For example, during the time that the balls A and B are in contact, each is pushing the other. Objects tend to fall toward the earth, but the earth at the same time tends to fall toward the objects. The paper bits and the rubbed body tend to approach each other.

Recognition of the Presence of a Force.—We have just shown that a tendency to acceleration may exist when there is no acceleration, as well as when there is. It is essential that we should know how to recognize the presence of a force in all cases. There are two methods:

1. By the acceleration produced.
2. By showing that there is a counterbalancing force.

The first method detects and studies any unbalanced force—i. e., one acting on a body free to move. The second detects as far as possible any balanced force—i. e., one acting where the body is not entirely free to move. As balanced and unbalanced forces often exist together, both methods must be applied in all cases.

Force recognized by Acceleration.—If a free body is acted upon by force, its motion will be accelerated or retarded as long as the force continues. Hence, if a free body shows acceleration, we know that a force must be present (that is, that energy must be acting on the body); and so long as the acceleration continues, we know that the force is operating. Let us examine the case of a freely falling body, and see how we recognize the presence of the force which we call its weight.

Ask some one to drop a good-sized white stone or ball from a high window, signaling to you the exact instant of dropping it, while you stand at some distance and watch its fall. Have the experiment repeated, until you become accustomed to the motion of the object, so that you can observe it well.

You will soon see that the motion is accelerated. The ball at the start moves very slowly (you must observe closely to see this), but rapidly gains speed, and during the latter part of the fall moves so fast that you can hardly follow it with your eye. Thus, the motion is accelerated, not only at the start, but throughout the fall. Hence there must have been a force (and therefore energy) acting throughout the fall. Moreover, as the ball started from a condition of rest, without effort of the person holding it, and as it will start at any desired instant, there must be a force acting *always* upon it.

As the experiment will succeed at all times, in all places, and with all objects except feathers, etc., whose motion is prevented by buoyancy or other known causes, we may generalize, and say that all objects near the earth appear to be always acted upon by a force (caused by energy of some kind) drawing them toward the earth. This force is what we call Weight. As before stated, it is a force acting between the earth and the object—i. e., tending to make the earth and the object approach each other.

Weight is, therefore, a force which acts always on all objects near the earth. That everything has weight, is one of the most familiar facts of our common knowledge.

Forces recognized by means of a Counterbalancing Force.—We naturally ask whether there are not some means of recognizing the existence of a force without allowing acceleration to occur. The answer is that there are. To show what the means are, we have first to show that forces can be balanced or neutralized by, and only by, other forces.

Balanced Forces.—If two equal and opposite forces be simultaneously applied to a free body, its motion will be unchanged. Two such forces are called *balanced forces.* This may be illustrated by the following experiment:

Over a pulley, P, moving with little friction (a round stick, such as a broom-handle or even a lead-pencil, will answer very well), hang two bodies, A and B, of equal weight, and connected by a cord. Neither will rise or fall. But A, for example, is pulled downward by a force (its weight). Why is it not accelerated? B by its weight pulls downward on the part of the cord at D. This portion of the cord pulls on the part next beyond, and this in turn on the next section, and so on around to C, where the cord pulls upward on A by the same amount (neglecting friction) that B pulls downward. But B pulls with an amount equal to its weight, and this is equal to the weight of A. Hence, A is pulled upward with a force just equal to its weight, and exactly opposite in direction. The acceleration of A which would have been produced by its weight is thus prevented by the application of an equal and opposite force. The upward pull on A by the string, and the weight of A, are then two balanced forces. The same statement is true of B. The balanced forces, therefore, can not start the bodies.

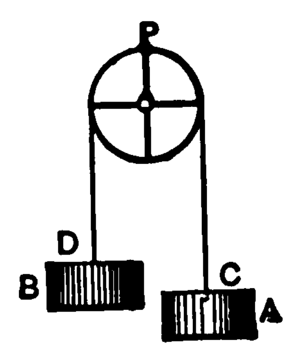

FIG. 12.

If you push up on A or B, the whole system will be set in motion. When you stop pushing, all acceleration will cease, and the motion would continue uniform, if it were not for friction, showing that the balanced forces can not change the speed of the bodies when moving.

Make the weight B a little greater than A. Then the upward force on C will be greater than the downward. Notice that A will be

started upward—that is, in the direction of the unbalanced portion of the force. Similarly, if the weight B be made smaller than A, the excess of force will be in the opposite direction, and A will move down. In each case the force has, of course, to accelerate both A and B, and both move in the direction of the greatest force upon them.

From these and similar experiments we may conclude that, to prevent acceleration in a body which is acted upon by a force, there must be applied an equal force in an exactly opposite direction.

Suppose, therefore, we find at any time a body which we know is acted upon by a force, and which is not being accelerated. Then we know that the body is also being acted upon by a force equal and opposite to the first. Even if the body is being accelerated, the acceleration may be due to some unbalanced part of all the forces acting upon it, and may not be the result of a single force only.

This affords us a means of recognizing the existence of forces, without allowing the acceleration to be produced. Anything which can be balanced against any known force must itself be a force. We have one convenient recognized force to begin with, viz., Weight.

QUESTIONS.—What is meant by tendency to acceleration ? To what must such a tendency always be due ? Give an example of a brief tendency to acceleration. Of a continuous one. Can a tendency continue after the energy causing it has ceased to act ?

What is denoted by the term Force ? Define force. To what is force always due ? Can there be any force where there is no energy ? What is the sole cause of force ? Can force exist by itself ? Are force and energy the same thing ? Would it ever be correct to use one term for the other ? Why do we speak of the effects of energy upon bodies as the effects of the force (i. e., the tendency to acceleration) which the energy produces ? Is force ever the real cause of any effect ? Why not ? What is the cause ? What do we mean by the term line of action of a force ? What is the direction of the line of action of weight ? Give some examples of forces. Is it found that a force ever acts on only a single particle of matter ?

In what two ways may we recognize the presence of a force ? Prove that weight is always acting upon any object near the earth. What is weight ? Is it energy ? Is it due to energy ? To what particular kind of energy is it due ? If we see a body moving with retarded motion, how do we know that it is being acted upon by a force ? How do we know that a body which is being accelerated or retarded is being acted upon by energy ? Why do we speak of the same case of acceleration sometimes as due to force, sometimes as due to energy, and yet say that energy and force are not the same thing ?

What is meant by balanced forces? Give an illustration of two forces balancing each other? How can we prevent the acceleration of a body acted upon by a force? Is there any other way? If we find a body which we know to be acted upon by a force, but which is not moving, what inference do we draw? How does this enable us to recognize other forces?

EXAMPLES OF FORCES.

Elasticity.—When objects are stretched, compressed, bent, or twisted, they tend, as a rule, to spring back to their original or normal size and shape. A continuous force is necessary to prevent their doing so. If the objects are stretched or compressed too much, they take up permanently a stretched, compressed, or bent shape; but with this permanent change we are not at present concerned. The property of tending to resume the normal size or shape is called Elasticity. It is due to forces which are brought into action by the change in size or form. These are known as elastic forces, or forces of elasticity.

Elasticity of Stretch.—A force due to Elasticity of Stretch, or Extension, is exhibited by all solids when under stretch.

Fasten a rubber band to a nail or hook in the wall. Attach to the lower end of the band a stone or any convenient object (Fig. 13). What occurs? The band stretches by a certain amount, and then, if strong enough not to break, stops, holding the body up from falling. Mark two points on the band with a piece of chalk, one near each end, and measure their distance apart when the object is hanging on the band. Take off the object and hang it on again. Measure once more the distance of the points apart. Try the experiment on another day, in another place, and under a variety of conditions. You will find that the band is always stretched equally by the same object. If you use a lighter object, the stretch will be less; if a heavier one, it will be greater.

FIG. 13.

The Object hung on the Band has Weight, which is prevented from producing acceleration after the band has stretched to a certain amount. The weight must, therefore, be counterbalanced by an equal and opposite force. The rubber band must pull upward just as strongly as the object pulls downward. The particles of the rubber, when stretched from their original positions, show a tendency to return. This force is greater the more the band is stretched, and is zero when the band is not stretched at all. It is therefore a force which is called into action more and more strongly as the particles of the rubber are pulled farther apart, and it is due to the elasticity of stretch. It is exhibited by all solids, and to some extent by liquids.

Instead of a rubber band, use a spiral spring. It will be stretched in a similar way; but this is really a case of combined bending and twisting. Or use a string, a straight wire, a glass rod, or a piece of any solid substance, either large or small. It will be stretched just as the band was; but you will not easily discover the fact, for the stretch will be so small that it can not easily be appreciated. With proper apparatus, however, it can be seen and even measured.

Elasticity of Compression.—A force due to Elasticity of Compression is exhibited by all solids, liquids, and gases, when compressed.

Place a thick piece of rubber on the table. Lay a heavy object on the rubber. Notice that the thickness of the rubber is made less. If in place of the rubber we were to use any other object strong enough not to break, it would be similarly in a state of compression and would be exerting a force due to elasticity when the object rested upon it. The compression can sometimes be seen, as in the case of rubber, but is often so slight as to require delicate apparatus to measure it.

As the acceleration which the weight would produce is prevented, the compressed solid must be exerting a force equal and opposite to the weight of the object. The particles of the rubber are brought nearer together and show a tendency to move back to their original positions. This tendency constitutes the force of elasticity of compression.

Elasticity of Bending.—When a solid is bending, the forces of elasticity of stretch and compression are both exhibited.

Fasten one end of a long, slender rod of wood (about a yard in length and half an inch on a side) to a table by means of a clamp or nails. Hang a heavy object on the end. This end will move downward to a certain point, and after a few vibrations will come to rest there. The rod will be bent into a curved form. In this condition

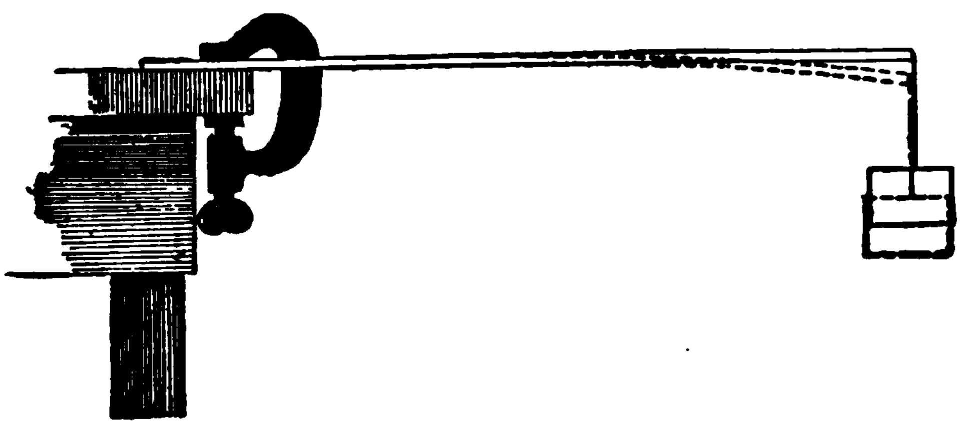

FIG. 14.—ILLUSTRATING ELASTICITY OF BENDING.

the upper layers of the wood (*convex* side) are in a condition of stretch; the lower layers (*concave* side) are in compression. You can illustrate this by bending a twig in your hand and examining the appearance of the upper and lower sides as you bend it. The elastic forces called into play in bending are those of compression and stretch.

Elasticity of Torsion or Twisting.—When any solid is twisted, it exhibits a force due to Elasticity of Torsion.

Take hold of the end of the wooden rod of the last experiment, after removing the weight. Twist the rod without bending it. The more you twist it, the greater force you have to exert. When you let go your hold, the wood untwists. The operation of twisting changes the relative positions of the particles, which, when thus treated, show a tendency to return to their original positions. This is another exhibition of elastic force, and is called elasticity of torsion.

All Elasticity is of the Same Kind, although appearing in somewhat different ways. It is doubtless due to some form of energy which gives the molecules a tendency to move toward one another when they are separated, or away from one another when they are crowded together by

the action of force applied to the body. As to just what this form of energy is, nothing is known.

In the examples of elasticity, the force applied to produce the stretch, compression, etc., was the weight of some object. That force was used merely for convenience; any other might have been employed. For instance, we might hang on the rubber band a piece of iron; the band will be stretched to hold the weight of the iron. If the magnet be now brought up beneath the iron, the band will be further stretched by the action of magnetic force between the iron and the magnet.

We must remember also that the band when hanging is somewhat stretched by its own weight alone; similarly, the block of rubber is compressed and the wooden rod bent slightly by their own weights.

From these experiments, and others of the same nature, it follows that whenever we see any object under Stretch, Compression, Bending, or Twisting, we may be sure that a force due to elasticity is being exerted. Thus we have added these to our list of recognized forces, and can use them in turn as a means of recognizing others.

Think out for yourself how the table is compressed when an object is laid upon it; how the hook is bent upon which the rubber band is hung; how the floor bends when you walk over it; how a bridge yields when a heavy load crosses it, as also under its own weight; and any other cases of stretching, compression, bending, and torsion, which may occur to you. Try in each of them to recognize the fact that an elastic force is being exerted.

Forces occur under various conditions of matter. They are not indestructible in the sense that matter and energy are, but may be made larger or smaller in amount or in many cases annihilated altogether.

Always remember that force is merely a condition of matter which is due to the action of energy. When we find a force, we at once inquire what the energy causing the force is. This question we can answer definitely in a few cases only. In most instances, our knowledge of the exact nature of the motion causing different forms of energy is very incomplete. A few other examples of forces will now be

given, especial attention being called to the fact that at least *two bodies* are concerned in every force.

Electric Attraction and Repulsion.—Suspend two pith-balls from glass rods or tubes mounted in wooden blocks, as shown in Fig. 15, using very fine silk thread (undyed floss or cocoon-fiber is best).

Touch the balls with the fingers to remove all electrification. They will then hang straight down as at *a* and *b*, with the threads vertical. There is no electric force between them; they do not tend to approach, or recede from, each other.

Now, electrify *a* by bringing against it a piece of vulcanite which has been briskly rubbed on dry silk or fur, and thus electrified. By allowing *a* to roll over the rubbed surface several times, it will become thoroughly electrified. Take care that *b* does not touch the vulcanite, or, if it has done so, hold it for a moment in the fingers to remove the charge of electricity. Then move the stands up toward each other, as in the figure. The threads will no longer hang vertical, but the balls will move toward each other and hang in the positions *c* and *d* instead of *a* and *b*. This shows that there is a tendency for *a* and *b* to be accelerated toward each other—that is, that there is a force of attraction between them. The ball *a* was the one electrified; but the force due to its electrified condition is not simply a tendency of *a* to move toward *b*, or of *b* to move toward *a*, but it is a tendency of both *a* and *b* mutually to approach each other.

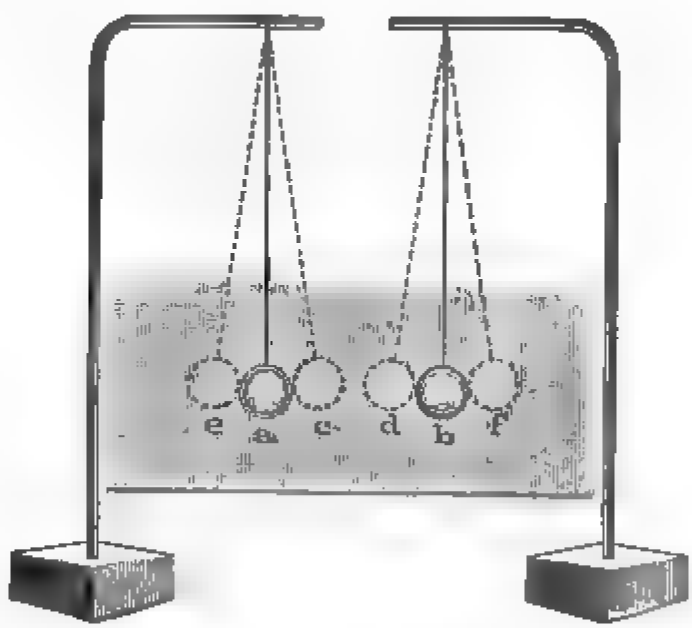

FIG. 15.—ATTRACTION AND REPULSION OF PITH BALLS.

Next roll each of the balls in the fingers for a moment; they will then hang in their original vertical positions without attraction or repulsion. Thus we have been able to produce force and to destroy it.

Electrify both balls by touching them with the rubbed vulcanite, and bring them toward each other. They will now tend to move apart and will hang in the positions *e* and *f*, showing that there is a repulsive force between them. Other interesting experiments with the pith-balls will be suggested when the subject of electricity is reached.

Magnetic Attraction.—Provide yourself with a magnet and a nail. Bring the nail and one end of the magnet gradually toward each other. When they are near together, you will feel that they tend to approach; you will have to hold each back, or they will rush together. There is, then, a force of attraction between them, and this force is greater the nearer they come together, being imperceptible at a distance of a few inches. It is called *magnetic force* or magnetic attraction, and is due to magnetism.

The Earth tends to approach a Body as well as a body the earth. We can not readily show this by the method of watching their motions; but we are very well assured of the fact by other knowledge which we possess regarding similar actions. We know that the moon revolves around the earth, that the earth and other planets revolve around the sun, that some stars form pairs revolving about each other. For certain reasons we believe that every particle of matter tends to approach every other particle, the amount of the tendency depending on the mass of the two particles and their distance apart. This, when fully stated, is called the Law of Gravitation.

Starting from this assumption, we must believe that the earth, moon, sun, and all the planets, attract one another with amounts depending on their masses and their distances apart at any given instant. If there were only one planet, it would move about the sun in a perfectly regular path. If there were two revolving at different distances and in different times, then their motion would not be perfectly regular, but when they were near together each would disturb the position of the other, now slowing, now increasing, its speed, and also moving it more or less aside from its simple path.

Imagine several planets, as in our Solar System, and you will see that the irregularity introduced into their otherwise simple motion

must be very complicated. Their paths are disturbed by their mutual actions, and the orbit of our moon is particularly so. Yet astronomers, basing their work wholly on the law of gravitation, are able to compute the position of the moon for any given time several years in the future. We therefore have here a remarkable piece of evidence that the assumption of the law of gravitation is correct; and this assumption involves the idea that at least two bodies are necessary to produce this kind of tendency to motion, and that each of the bodies concerned has an equal tendency to move toward the other.

FORCE CHANGING DIRECTION OF MOTION.

Effect of Force inclined to Direction of Moving Body.—In the cases of balanced forces, the lines of action of the forces have been in opposite directions. Let us see the effect of force inclined to the direction of a body's motion.

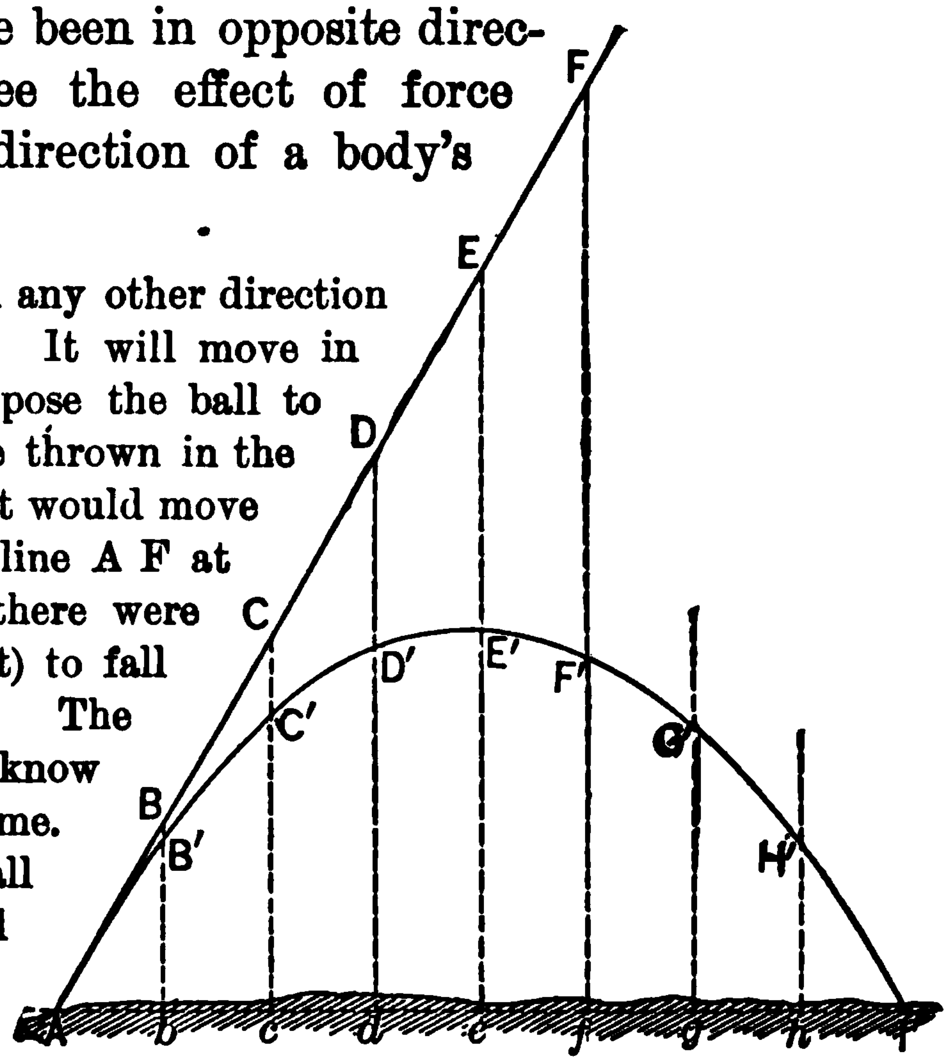

FIG. 16.—ILLUSTRATING CHANGE OF DIRECTION.

Throw a ball in any other direction than a vertical one. It will move in a curved line. Suppose the ball to start at A and to be thrown in the direction of A F. It would move along this straight line A F at a uniform rate if there were no tendency (weight) to fall toward the earth. The weight, however, we know was acting all the time. We find that the ball travels in a curved path A B′ C′ I′.

If the ball had been thrown horizontally, it would have moved in the path A *b c e* of Fig. 17. If thrown obliquely downward in the direction A E, Fig. 17, it would have moved in the path A B′ C′ D′. In all cases, the motion is in a curved path. Notice that the direction of action of the weight, being vertically downward, is always *inclined* to the path, while in the case of a body moving verti-

cally upward or downward the weight acts in *the direction* of the path. Hence, when the force acts in the direction of the path, the motion is not changed in direction but only accelerated or retarded. When the force is inclined to the path, the direction of motion is continually changed.

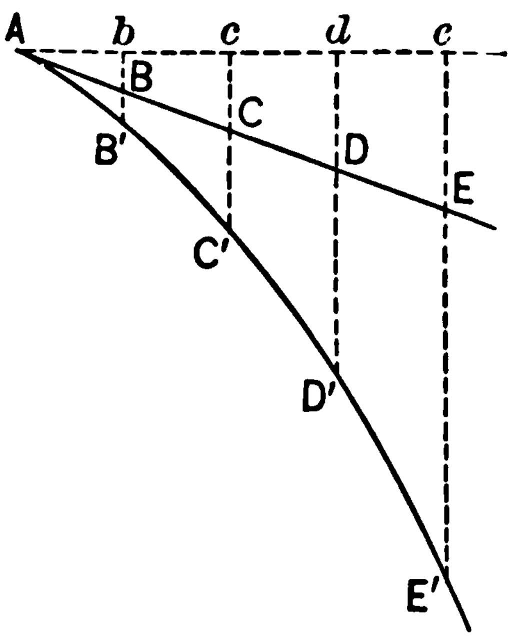

FIG. 17.

It will also be seen by inspection that the motion in the three cases above is accelerated or retarded as well as curved; but if the force is exactly and always at right angles to the path, the velocity is uniform, although the direction is continually changing. This is the case of a body revolving uniformly in a circle. It may be illustrated by whirling around a stone on the end of a string.

QUESTIONS.—What is elasticity? What are the forces of elasticity? Show that a stretched object exerts a force tending to restore it to its normal size and shape. If a weight is hung on any object whatever, is the object stretched? Is it exerting a force? Answer similar questions for compression, bending, and twisting. What is the particular form of energy causing the elastic forces? As you stand upon the floor, does the floor exert an upward force against your feet? How much force does it exert? To what property of the floor is the force due? Does the floor push upward against the table standing upon it? Why is not the table moved upward by this push?

Does a mountain press upon the earth beneath it? If the upper layers of the earth press upon those beneath, what must be the amount of pressure upon layers several miles below the surface? When a train passes on a bridge, how much does it press upon the bridge? Can the bridge be prevented from bending slightly? How does the bridge balance the weight of the train?

Show that, when an electrified pith-ball hangs near another pith-ball, the balls attract each other. Does one attract more than the other? How can you prove that the attraction between a magnet and iron is mutual? Give reasons for believing that weight is a force pulling the earth and the object toward each other, and not merely pulling the object toward the earth. When an object falls, does the earth move upward toward it? Describe by diagram the experiment showing that force changes the direction of motion of a body.

PRODUCTION OF FORCE BY ENERGY.

Acceleration and the Tendency to Acceleration, it must be remembered, are caused by the action of energy, and can result from nothing else. This action of energy has already been called Force. In order that you may better

understand how it is possible for energy to produce force, and why we believe that force is wholly due to energy, consider carefully the following illustration:

Hold a bat or a board in your hands and let some one throw against it an elastic ball. To prevent the board from moving when the ball strikes it, you will have to push against it. The ball exerts a force during impact. Suppose a large number of elastic balls to strike the board in rapid succession. You will then have to exert a continuous push to hold the board steady. If the board is held in place by springs, these springs will be compressed until the pressure which they exert, owing to elasticity, will be just equal to the pressure or force caused by the striking balls. The compression will be kept up as long as the bombardment of balls continues. It is thus clear that a continuous bombardment of balls can produce a sensibly continuous force.

Let us see what becomes of the Energy of the balls when they are producing force:

First, when the board is stationary. If we had suitable means of measuring, we should find (provided board and balls were perfectly elastic) that the balls rebound with just the velocity, and therefore just the energy, with which they strike. They therefore lose no energy when producing force if the body acted upon is stationary. *The mere production of force does not require the expenditure of energy.* The only change made is in the direction of motion of the balls.

Secondly, when the balls are allowed to accelerate the board. Again, if we could measure, we should find that when the board is moving in the direction in which the balls tend to make it move, they will rebound with less velocity than that with which they strike, and therefore with less energy. They are thus giving up energy to the board, which, if free to move, will be accelerated just as was the ball B (page 31). The acceleration of the board will be such that it will gain energy at just the rate at which the striking balls lose it. The energy expended by the balls is simply transferred or given up to the board. The force exists as before, but no energy is expended in maintaining it.

We thus see how energy like that of the bombarding balls can accelerate a body—i. e., can do work.

Thirdly, when the board is pushed back against the balls. Here the same amount of force exists as in both the other cases; but now each striking ball rebounds with greater velocity than that with which it strikes, and therefore gains energy. To push the board back will require an application of energy, which is transferred to the system of balls in the shape of increased energy of motion.

Fourthly, where the board is allowed to be moved back by the balls with a uniform motion. In this case the force will be present as before. The balls will also rebound with less than their striking velocity, and will therefore give up energy to (i. e., do work upon) the board; but as the board is moving with a uniform velocity, it is not accumulating energy as in the second case. The energy here can simply be transmitted through the board to some other object.

In all these cases, if we had merely seen the compression of the springs or felt that we were obliged to push, and had been ignorant or unconscious of the energy on the other side of the board, we should have been aware only of a condition which we have already recognized in other cases as due to force. We should naturally, therefore, have spoken of the force as causing the acceleration, doing the work, and being worked against; but it is evident that such a statement would have been imperfect. This illustrates the position we are in respecting weight, elasticity, etc. We perceive the force by methods already given, but are ignorant of the exact nature of its cause. We speak of weight and other forces as doing work, while the real agent is energy of some kind which is causing the force in question.

The illustration just given is a purely imaginary one, although entirely practicable; but we have in nature a force which is explained on precisely this principle. It will be shown, when gases are treated, that a gas, for example air, in an inclosed space, exerts an outward pressure upon all the inclosing walls. This pressure is explained as being due to the bombardment of the walls by the molecules of the gas in their violent to-and-fro motions described on page 37.

We are not, of course, to assume that, because the bombarding balls enable us to perceive how energy *may* and sometimes does cause

force, therefore all force is produced by just such a process. It is probable that this is not true, but that the form of the energy causing such forces as weight, elasticity, magnetic and electrical attraction, etc., is or may be very different from a process of bombardment.

The argument from which results the belief that force is always caused by energy is—first, that it is strictly in accordance with the principle of the conservation of energy (page 39); second, that it leads us into no contradiction with observed facts of any kind, but, on the contrary, enables us to explain many facts that can not be so well accounted for in any other way.

QUESTIONS.—Define force. On what only does it depend, and in what does it always manifest itself? Give an illustration showing that energy is the cause of force, and that force is wholly due to energy. Do we understand the source of every manifested force? Why? Does the production of force require the expenditure of energy? In pushing a board back against striking balls, what becomes of the energy applied? Sum up the four cases in which the energy of striking balls produced force, and explain the transfer of energy in each. In these cases, had we been ignorant of the energy, to what would we have ascribed the visible effects? State a parallel case from the properties of gases. Can we assume that all force is similarly caused? Advance the argument from which results the belief that all force is produced by energy.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Throw a ball straight upward. Is its condition the same going up as coming down? In what respect is there a difference? Does the same tendency of acceleration toward the earth exist in both cases? Does the ball weigh the same whether moving upward or downward?

Prop up a smooth board on the floor and lay a marble on the elevated end. Release the marble, and as it rolls down the board what will it show? Draw chalk-marks across the board at equal intervals, and you will perceive the change of speed more readily. To what is the motion of the ball here due?

Hang up the rubber band as explained. Fasten to its lower end a small piece of iron. The band will stretch slightly till its elastic force balances the weight of the iron. Now bring your magnet carefully up under it. The band will stretch further, showing a stronger pull by the iron than that due to its weight. If the magnet is brought close enough, the iron will be pulled up into contact with it. Then, if you pull downward, you will find that the band is stretched considerably, and may even break before the iron can be separated from the magnet. Does the rubber exert a counterbalancing force? How?

Hang your magnet on the rubber band and then bring a nail up toward it. The band will be stretched. What does this show? Can the force exist unless both bodies are present?

With a horizontal wind, your kite rises. Draw a diagram showing the action of the forces in operation.

PROPERTIES AND CONSTITUTION OF MATTER.

ESSENTIAL PROPERTIES.

By the Study of Material Objects it is found that they possess certain characteristics called properties.

The Essential Properties of Matter.—Some of these properties characterize all objects in common—that is, if any object whatever be examined, it will be found to have

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NOTE.—In the picture above are represented a number of simple pieces of apparatus, with the help of which, together with such contrivances as may easily be improvised from materials found in every household, the pupil can perform for himself the experiments described in the following sections on the Properties of Matter, Dynamics, Gravitation, and Machines: No. 1 represents a wooden wagon, with pulley and scale pan; 2, a grooved board with ivory balls; 3, a pulley and weights; 4, a pole with weights supported by spring-balances; 5, apparatus for equilibrium of moments of forces tending to produce rotation; 6, a piece of cardboard hanging on a pin, with plumb-line in front, for finding center of gravity; 7, a block of wood, with string attached to slide on board, for illustrating the laws of friction; 8, a balance, 9, pendulums; 10, pulleys of different varieties. This apparatus may be largely constructed by any ingenious pupil who can handle carpenter's tools, or the outfit may be obtained from any reputable dealer in optical and philosophical instruments.

them. Moreover, in whatever way it is treated, whether it is chemically separated into its constituents or combined into other compounds, the resulting substances will still show these properties. So far as we can perceive, they belong to any portion of matter, however small, even to a single atom. Thus they appear to be properties of the matter of which objects are made up, and, as far as human knowledge extends, there is no form of matter which does not possess them. These *essential* properties are Mass, Extension, Impenetrability, Indestructibility, and Inertia.

There are certain other properties which appear to belong to *bodies* (collections of atoms), but not to be essential to *matter itself*, and therefore not to characterize single atoms. Some of these Properties of Bodies, such as Density, Divisibility, and Porosity, are merely facts or hypotheses concerning the structure of bodies. Others, like Hardness, Ductility, Transparency, Electric Conductivity, relate to the qualities which the bodies show when treated in certain ways. Still others, like Gravitation, Cohesion, Elasticity, etc., are conditions of matter due to the action of energy. It is useless to attempt to enumerate all these properties of bodies; they will be considered one by one as the study of the subject progresses.

Mass.—If you were to ask *how much* of a certain material substance existed, and the reply were made none, you would, of course, understand that the substance did not exist. By the question "how much," you mean *what quantity*. The property of having quantity is therefore essential to matter; but the term *mass* stands simply for quantity of matter (page 11). So we may say that mass is an essential property of matter.

Extension is the property of occupying space, or, in other words, of having volume (length, breadth, and thickness). We recognize easily that almost every material object has length, breadth, and thickness, and thus occupies or fills up more or less completely a portion of space. Some objects are so small that we can not see them with the unaided eye; but it is impossible to think of them as not hav-

ing volume. So accustomed are we to this idea, that, if any one were to say that a body occupied no space, we should declare at once that it did not exist.

Many things which are too small for us to appreciate with the eye can be seen with a magnifier. We have reason to believe that there are other objects too small to be seen even with the most powerful microscope, yet we realize that they occupy a minute portion of space. We know that some things are so thin that they seem to have no sensible thickness; but if we imagine many hundreds or thousands of them piled together, we may be sure that they will have a perceptible thickness. Thus, gold-leaf is so thin as to appear of no sensible thickness to the touch; but if several hundred thousand sheets of it were piled one upon another, the whole would have a thickness of an inch or more. This shows that each sheet has thickness. The idea of occupying space is thus one which is inseparably associated with our idea of matter. We can not conceive of any portion of matter, however minute, which would not have some volume.

Impenetrability.—We have seen that matter occupies space. We also believe that no two atoms of matter can occupy the same portion of space at the same time. It has been further shown that the molecules or atoms of matter are probably never packed solidly together, but, on the other hand, have always spaces between them. When we say, then, that no two atoms can occupy the same space at the same time, we do not mean to apply the statement to material objects or bodies composed of many atoms. The atoms of two bodies can not occupy the same actual portion of space; but the atoms of one body may lie in the spaces between the atoms of the other, so that two bodies may have just the same apparent volume as one. This will be more fully explained in the section on Porosity.

To illustrate impenetrability, take any object, such as a stone or a piece of wood. Varnish it, if necessary, to keep water from entering its cavities; immerse it in a tumbler full of water. The water will overflow, being displaced by the object. The volume of the displaced water will be exactly equal to that of the immersed solid. Invert a tumbler; force it mouth downward into a dish of water. The water

does not enter, because of the air in the tumbler. The air acts as a solid, except that it is somewhat compressed by the water pressure, as you will see on examination. These experiments illustrate the familiar statement that two bodies "can not occupy the same space at the same time." But the true idea of impenetrability has reference to the atoms of matter rather than to bodies.

Indestructibility.—Conservation of Matter.—The fact that matter is indestructible can not easily be proved at this stage of our studies. The assertion must be accepted as true, although seemingly contrary to experience.

Stand a tumbler of water on the table and leave it for a day or two. The water disappears gradually, and you can not see what has become of it. It appears to have been destroyed; but it has only passed off into the air in the form of invisible vapor The vapor is still the same substance as the water; the molecules of the water vapor and of the liquid water are exactly the same. The difference between the vapor and liquid is only that the molecules in the vapor are very much farther apart than in the liquid (a cubic inch of the liquid water making over 60,000 cubic inches of vapor at the ordinary room temperature). Thus the vapor can not be distinguished by the eye from the air of the room.

Now, how can we tell that the water still exists in the air? Take a tumbler of ice-water, or, better, a piece of glass, a spoon, or any object which has been lying in some very cold place. Wipe it dry on the outside without warming it, and hold it just above the water in the tumbler. There will very quickly appear on its surface a coating of fine particles or drops which you will recognize as water. The cold surface has collected the molecules of water from the air into the liquid form, or, as we say, has condensed the vapor. You see every day a layer of moisture on the pitcher of ice-water, or on the cold window-pane a coating of dew or frost. This is water or ice, produced by condensing from the air of the room the moisture or water vapor which has evaporated from the surface of water in the room or elsewhere.

When water disappears in this way, then, it is not destroyed, but merely changed into a different condition, in which we do not happen to be able to perceive it so readily. The same change takes place when water boils away, when clothes dry, when ice and snow evaporate. The vapor is often condensed in the air itself, and we see what we call rain, clouds, mist, and fog. These are all made up of particles

of liquid water more or less fine, produced by the *condensation* of the vapor as it is chilled by some process which happens to cool the air.

Another way in which matter appears to be destroyed, but is not, may be studied in the chemical changes that take place in combustion or burning. Wood or coal when set on fire continues to burn until nothing is left but ashes. A pile of wood will leave an amount of ash so small that you can lift it with hardly a thought that it has any weight. The ashes then retain only a small part of the matter which made up the wood. Where has the rest of it gone? Has it been destroyed? In one sense it has, for it no longer exists as wood. A building burned to the ground is destroyed as far as its usefulness as a building is concerned. But in neither case has the *matter* contained in the object been destroyed. There is just as much matter as before, but its *form* has been changed.

The wood has been converted partly into water vapor, partly into invisible gases, and partly into ash. If we should measure the mass of the wood with which we start, and then could collect all these various substances formed by the burning and in any way measure their mass, we should find that this is considerably *greater* than the mass of wood. Thus we have not only as much matter as in the wood with which we started. but in reality more, because some oxygen gas from the air combined with the wood as it burned. If the mass of oxygen used were also measured, we should find the sum of this and of the original mass of the wood to be just equal to the mass of the substances collected after the combustion. It would thus have been proved that the mass (amount of matter) is absolutely unchanged, although the form is very different. Many experiments of this sort have been made; but the most conclusive proof of the indestructibility of matter is to be found in the fact that all over the world chemists, physicists, and artisans, are working upon processes which would surely fail if matter were not indestructible.

The fact that matter may change in form in an endless variety of ways, but that the total amount of matter does not change, is sometimes called the principle of the Conservation of Matter.

Inertia has already been somewhat discussed (pages 30 to 32). We may explain it by saying that a particle of matter possesses absolutely no power to change its velocity or direction of motion. If the velocity and direction of motion of any material particle or body does change, it is because of the action of energy upon it. The general law which expresses the property of inertia is Newton's first law of motion (see page 31). This law is based wholly on experiment; but we find very conclusive evidence for it also when we consider what would happen if a body had power to move itself. Such power would involve a suspension of the laws of energy, if not an annihilation of energy itself.

Start a ball rolling (without any twist or spin) along a level floor, or, better still, on smooth ice, and watch its motion. Notice first that it moves *in a straight line.* Unless it meets with obstacles, it does not move upward, or sidewise, or backward. To think of it as jumping upward, or stopping of itself and moving backward, strikes you as absurd—which is only a proof of the uniformity of your experience to the contrary. The ball can not move downward, because of the floor or ice; we know that its tendency to move downward is not due to itself, but is owing to an action in which the earth is concerned, and that the floor merely counterbalances this action. The floor does not in any way alter the motion of the ball. If the earth were not present, there would be no need of the floor. The ball, then, moves onward in the direction in which it started, merely because nothing acts to change that direction. It does not of itself tend to change the direction of its own motion. This is one evidence that it is inert.

Notice next that the ball keeps on moving over a long distance; and that the smoother the surface upon which it rolls, the farther it will move when started with the same speed. Now we know that there are two actions which tend to stop it. These are the resistance of friction against the floor and the resistance of the air. We can diminish the first by experimenting on a smoother surface, and make the second less effective by using larger and larger balls. We find as we do so that the distance the ball will go increases, and we may therefore infer that if we could entirely remove these resistances the ball would continue to move at the speed with which it started, and that it would move with uniform velocity. The ball does not, therefore, of itself tend to change its speed. This is a second evidence that it is inert.

Take another example: Throw a ball or stone horizontally. It does not continue to move in a straight line and with the speed of starting, but falls in a curve toward the earth and slows up in speed. Now, we find by experiment that it falls toward the earth just as fast as it would if dropped from the hand and not thrown horizontally. Hence its curved motion is wholly due to its falling toward the earth, and this is caused by the energy of gravitation, and is therefore not due to the body itself alone. Its slowing up in speed is caused by the resistance of the air. Hence we infer that, if these two actions in which outside bodies share should be removed, the ball would go on in a straight line with its original velocity.

Select for yourself and study out other examples.

Inertia may be further illustrated by piling up half a dozen books with a smooth-covered one at the bottom. Slide them swiftly across the table-top by pushing against the bottom one. Place an obstruction in the way, such as the other hand held firmly down against the table, and let the bottom book strike against it suddenly. What becomes of the top books? How is this due to inertia?

Pile up the books again. Push the bottom one violently. What becomes of the top ones? Why?

Passengers often stand in the aisle of a railroad-car as it is approaching the station. When the car stops with some suddenness, they plunge violently forward and sometimes fall. Why? They generally say that they are "thrown" about in such a case. Are they thrown in the sense that a ball is thrown from the hand? A railroad train in motion will not stop until it has expended all its energy of motion in heat and other forms of energy at the brakes, on the rails, in the air, etc. This may be said to be due to its inertia.

All these and similar examples should show you how energy depends upon inertia; but inertia is only the property, and energy is the thing. Neither is due to the other.

QUESTIONS.—Name the Essential Properties of matter. Why are they properties of matter rather than of objects? State some properties that characterize bodies and not the atoms of which they are composed. What is Mass? Extension? What is meant by Volume? The dimensions of a body? Have microscopic objects length, breadth, and thickness? Perhaps your teacher or some friend will let you look through a microscope at objects too small to be seen

with the unaided eye. Prove that a sheet of gold-leaf has thickness. Define and illustrate Impenetrability. If you fill a tumbler to the brim with water and drop in a bullet, what will take place? What does this prove? Show how the atoms of one body may lie in the spaces between the atoms of another body.

What do we mean by the Indestructibility of matter? Illustrate by the evaporation of water from a tumbler; by the burning of wood. What has become of the matter contained in the objects apparently destroyed? Take the case of the oil burning in your lamp. Is a particle of its substance lost? What becomes of the body after death? State the most conclusive proof that matter is indestructible. What is meant by the Conservation of Matter? Explain Inertia. If a body had power to move itself, what would be the effect on the laws of energy? Illustrate inertia by the case of the ball rolling along a smooth floor; by the case of the ball thrown horizontally; by the case of the books pushed along the table. Did you ever notice the effect of inertia when a train was entering the depot or a ferry-boat landing in its slip? Why is it dangerous, when the horses are running, to jump from a carriage? *Because the feet cease to move the instant they strike the ground, while the inertia of the body carries it forward.* On what principle is the snow shaken from your arctics by kicking against the door-post? Can you think of other ways in which we avail ourselves of inertia?

CONSTITUTION OF MATTER.

Divisibility.—Any object may be cut or broken into pieces and these pieces may be made into others still smaller. This process of mechanical subdivision may be kept up until the substance is reduced to a powder, the limit being apparently only the lack of suitable means of making it finer. By hammering thin sheets of gold repeatedly between sheets of animal membrane, the gold-beater can reduce them to a thickness of only three millionths of an inch. By an ingenious process, a film of gold has been produced of a thickness estimated at one quarter of a millionth of an inch. The average diameter of the water-drops in a cloud causing the halo which you have often seen around the sun or moon is calculated to be one thirteen thousandth of an inch. Such was probably about the size of the dust-particles in the air which produced the remarkable sunset colors so noticeable in 1883–'84 after the Krakatoa eruption. Soap-bubbles, just before breaking, may be as thin as one fortieth of the millionth of an inch; and it has been computed that a half-pound of spider's web would encircle the earth.

All these facts go to show that matter can be divided into parts of extreme smallness or layers of extreme thinness, which is practically the same thing. This property is called Divisibility. But is the divisibility infinite? Can matter be subdivided indefinitely if suitable mechanical means can be provided? Or should we eventually come to a piece which could not be reduced to any smaller parts? If the latter be true, then matter is not infinitely divisible, but is "granular" in structure—that is, it is built up of separate individual parts. If matter is perfectly continuous, we can not explain the properties of compressibility and elasticity (see page 50). If it is granular, we can explain these properties, as well as many others, by assuming that the grains or ultimate particles are not in contact throughout the substance, but are separated by intervals.

There is a very wide range of chemical as well as physical facts which seem to require the hypothesis that our recognized kinds of matter are built up of parts or units called Atoms, each of which is of fixed mass. Many of these facts require that the atoms should be assumed, not to be in contact with one another, but at a distance apart which is generally greater than their own diameters. They also involve the assumption that these atoms are in to-and-fro motion and in rotation. The facts do not, however, require that the space separating the atoms should be empty, but admit of its being filled with a material offering no resistance to the motion of the atoms through it.

A hypothesis has been recently proposed (by Sir William Thomson in 1862) which seems to fulfill these conditions. It assumes that the atoms are rotating rings or vortexes of some given material. You have doubtless seen the rings of smoke sent up from the stack of a locomotive, and have noticed that the smoke composing these rings is always in rotation. If you follow the motion of any individual part of the smoke at a section of the ring, you will see that it moves upward on the inside of the ring, out over the top, down the outside, inward at the bottom, and again upward as before, thus whirling around in a circle in a vertical plane. A ring also frequently rotates as a whole around its axis. It is, moreover, often in vibration.

With an apparatus like the one pictured in Fig. 19, you can form and study such rings. Make a box of pasteboard or wood, about 8 inches broad by 8 inches high by 18 inches long, leaving both ends

open. Over one end of it stretch loosely a piece of cloth and cover the other end with a cardboard in which is cut a circular hole of four inches or more in diameter. Inside the box place a dish of strong ammonia and another of strong hydrochloric acid, the fumes of which

FIG. 19.—VORTEX RINGS, ILLUSTRATING THOMSON'S HYPOTHESIS.

will mix and form within the box a white cloud of smoke consisting of particles of ammonium chloride. Strike the cloth end of the box a tap with the hand. A puff of this smoke will come out at the open end and move slowly onward. Notice that it has the form of a ring whose particles are revolving just as in the smoke-rings from the locomotive. Tap again and send out another, then a third, and so on. By regulating the energy of the blows, you can make the rings move faster or more slowly, and can thus cause them to collide, move through one another, etc. Notice how they rebound on collision with each other, as if elastic, and how they change form on striking solid surfaces. They finally break up and are brought to rest, owing to the friction of the air, for they are really air-rings revolving in air, but made visible by the smoke. Such rings are called vortex-rings.

Thomson's hypothesis assumes that atoms are merely such vortex-rings existing in a homogeneous continuous material and consisting of it. These atoms are supposed to differ in many respects, especially in size, rate of rotation, and in the kind and amount of vibration which they possess, such differences being sufficient to account for the varieties of atoms or of matter which we recognize. The material is of such a nature as to have no friction between its parts, so that the vortex-

rings, once started, must continue forever and without change of character. It has been found possible to explain upon this hypothesis some of the fundamental properties and phenomena of matter.

Atomic Theory.—Atoms.—We are not obliged, for present purposes, to discuss the questions just suggested. Little is settled in regard to them, and the hypotheses advanced are very incomplete. We will, therefore, concern ourselves only with those few hypotheses which it is convenient to use as we proceed.

Let us assume—

I. That material bodies are built up of extremely minute particles of matter which are called Atoms.

II. That these atoms are not divisible—that is, that they are the smallest parts which can exist.

III. That every atom is indestructible and unchangeable.

IV. That atoms are of several kinds, each possessing its own characteristics; but that the number of kinds is limited, being, as far as is now known, about seventy.

V. That there are certain essential properties common to all atoms, and thus to all matter.

These assumptions are a somewhat incomplete statement of the hypotheses which form the basis of the so-called "Atomic Theory" of the constitution of matter. The complete theory embraces other hypotheses and offers explanations of many laws and phenomena. There are serious objections to it, and it is to be regarded only as a good working hypothesis on a very difficult subject.

Chemical Energy and Affinity.—The atoms of the different kinds of matter (elements) show a tendency to unite with one another and form *compound* substances. This tendency to combination is stronger between some kinds of atoms than others, and varies with temperature, pressure, and other physical conditions. It follows certain remarkable laws, which are explained in the study of chemistry, and is due to a form of energy called Chemical En-

ergy, regarding whose exact nature little is known. The forces produced by the action of chemical energy are called chemical forces or, more generally, Chemical Affinity. They are tendencies to acceleration among the atoms.

Molecules as distinguished from Atoms.—When, under the influence of chemical energy, the atoms of elements unite to form compounds, they appear to combine only into small groups containing a few atoms each. Such groups constitute Molecules. A molecule, then, is a group of atoms bound together by chemical energy. Thus, a molecule of water consists apparently of two atoms of hydrogen united with one of oxygen. It is evident, therefore, that if the molecules of a compound substance were to be broken up, the character of the compound would disappear.

Chemical study leads us to believe that, with few exceptions, atoms do not exist separately—that is, uncombined with other atoms—even in elementary substances. For instance, when hydrogen gas (an elementary substance) exists uncombined, its molecules are not single atoms, but consist of two atoms united by their chemical energy.

We may, therefore, define the Molecule of any substance as the *smallest portion of that substance which exists by itself*, and the Atom as the *smallest portion of any element which exists even in combination.* Thus any atom is of one kind of matter throughout.

The molecule of zinc, cadmium, mercury, and possibly of some few other elements, seems to contain only one atom. The molecule of most elements contains two atoms; that of phosphorus and of arsenic, four. The molecules of compounds contain different numbers of atoms, according to the complexity of the substances—sometimes as many as several hundred. It is probable that the molecules of gases are separate from one another; while those of liquids are somewhat tangled together into groups or. bunches, and those of solids are crowded still more closely.

Spaces between Molecules or Atoms.—Atoms and molecules are supposed not to be in actual contact with one

another, but to be separated by distances which are usually great as compared with the size of the particles themselves. Thus the apparent volume of a body is much larger than that which the molecules or atoms would occupy if packed solidly together. The latter appear to be kept apart, not by reason of any repulsion between them, but because they are in continuous to-and-fro motion.

Perhaps you can form an idea of how this can be by imagining a number of boys packed so closely together that there is no room to crowd in another. They would occupy a certain space on the ground. Now, let every boy try to move to and fro, each in a different direction, aiming to move back and forth through just one full step and no more, and let him change the direction at each step. With the exception of those on the edges, the boys will hardly be able to move at first; but those next the edges will gradually push out their fellows; these in turn will be pushed out by those farther in, and so on. The result you can easily foresee, and if you try the experiment you will find that the crowd gradually spreads over more space until each boy has the room he needs to move in. The jostling to and fro forces the boys apart and keeps them apart. You can see also that it would continue to keep them apart even if each boy had a slight tendency to move toward the center of the crowd rather than to remain where he was placed.

Thus the molecules of a solid substance are held apart from one another merely because they have a to-and-fro motion which they *must* keep up. The molecules are supposed to be like elastic balls, so that when they strike one another they bound off without loss of energy.

Porosity.—Fill a tumbler with shot, as in Fig. 20. Notice that the shot are separated by spaces or interstices; they do not fill the tumbler full. Imagine the shot to represent the molecules of a substance; then the spaces represent what are called the *pores* of the substance, and the property of having these pores is called Porosity. But the shot do not represent these pores properly, for, as just explained, the molecules are supposed not to be in contact as the shot are, but much farther apart. Hence the pores are much larger in proportion to the molecules than the spaces between the shot are in proportion to the shot. Let us examine some proofs that such pores exist.

Take a glass tube bent into the form shown in No. 13 of the collection of apparatus on page 178. The short arm of this tube is closed at the top, the long arm is open. Pour a little mercury into the long arm. It will fall to the bottom and inclose above it some air in the short arm. Pour in more mercury, and the volume of this air will be lessened. Pour in additional mercury, and you will find that the air is gradually reduced to smaller and smaller volume. We are then compressing the air—that is, forcing the same mass to occupy less space, or making the air more dense. Now, the only way in which we can picture this action to ourselves, if we regard matter to be impenetrable, seems to be by imagining the air to consist of particles or molecules with spaces between them, and inferring that when the air is compressed the molecules are simply brought nearer to one another. Solids and liquids are also compressible, but much less so than gases. Compressibility, then, seems to indicate that matter is porous.


FIG. 20. -TUMBLER OF SHOT.

It has been stated (page 63) that water vapor at ordinary temperatures occupies about 60,000 times as much space as the same mass of liquid water occupies. To understand this we must imagine the water as made up of molecules with spaces between them, which are much larger in the condition of vapor than in that of liquid. Thus the molecules of the vapor appear to be about forty times as far apart on the average as those of the liquid water.

Mix thoroughly together two exactly equal volumes of alcohol and water. The mixture might be expected to have just double the volume of either separately—that is, the sum of the separate volumes; but this will not be the case. The volume of the mixture will be about six per cent less than the sum of the two. This experiment may be made by filling a small flask with water, and then removing exactly one half of the water and replacing it with alcohol. The resulting liquid stands much lower than before in the neck of the flask. There are other liquids which show the same action.

Fill a tumbler with water. Put in a pinch of salt. After a few

minutes, water taken from any part of the tumbler will taste salt. The salt has been dissolved, as we say, by the water. How do we account for this? We suppose that the salt has become distributed through the pores of the liquid, or that the molecules of salt have passed off into and through the spaces between the molecules of the water and have thus become distributed into all parts of it. Sugar, blue vitriol, and a multitude of familiar solids, thus dissolve in water, as do also gases. The effervescence of soda-water is due to the bubbling out of carbonic-acid gas, which was held in solution under pressure but is given out when the pressure is removed.

In many cases of solution, the volume of the liquid after solution is less than its original volume plus that of the solid added.

Into the tumblerful of shot pour water, or finer shot, or sand, shaking it well. You can thus put a considerably greater mass into the tumbler, which has already as many of the original shot as it can hold. If these shot, instead of being in contact, were in some way held farther apart as the molecules seem to be, you could put still more material into the pores. The shot thus illustrate the porosity of matter, but only in a crude way, for the fact that the molecules are in motion and the shot are at rest makes a great difference in the conditions. Moreover, the molecules should not be imagined to be hard, spherical bodies. They are almost certainly not so, and we have no idea what they are like. Indeed, we can not be too careful to remember that all our notions about molecules are merely hypotheses.

Besides the Molecular Pores just described, bodies have cavities of sensible size which are often called pores. Thus, a sponge, a loaf of bread, a brick, wood, the majority of substances, even gold and granite, are full of such holes, and are therefore called porous. This is illustrated in the familiar process of filtering or straining. It is well, therefore, to bear in mind that there are two classes of pores, and to call the molecular spaces molecular pores, or, better, intermolecular (*between the molecules*).

Size of Atoms and Molecules.—There are phenomena which enable physicists to obtain an approximate idea of the number of molecules ordinarily contained in given volumes of certain substances, and even some notion as to the probable size of the molecules themselves. Imagine a

cube of water one inch on a side magnified until the length of its side is equal to the diameter of the earth. Then in this enormously magnified cube there would be one molecule to every cubic inch, and of this space the actual molecule itself would probably occupy about one twentieth. Another way of stating the size is to say that if a drop of water were magnified to the size of the earth, the molecules would occupy spaces greater than those filled by small shot, and less than those occupied by base-balls. Of these spaces the molecules would occupy about one twentieth, as before.

The smallest object which would be visible under the most powerful microscope is probably not smaller than a cube of one one hundred-thousandth of an inch on a side. Such a cube would contain from 60,000,000 to 100,000,000 molecules of oxygen or of nitrogen. This would mean twice as many atoms, as each molecule of these gases contains two atoms. Now, as the molecules themselves fill but perhaps one twentieth of this space, it is easy to understand that a single molecule is much too small to be seen even with the most powerful magnification which we can at present, or perhaps ever, produce.

Questions.—Explain Divisibility. Give some illustrations of the extreme thinness to which layers of certain substances can be reduced; of the extreme smallness of certain particles in the air. Is matter infinitely divisible? What do many chemical and physical facts require for their explanation? What do they involve as regards motion among the atoms? Are the spaces separating the atoms necessarily empty? State Thomson's hypothesis. Show how it may be illustrated with vortex-rings. How are the atoms supposed to differ, and to what do these differences give rise? State the five hypotheses that form the basis of the so-called Atomic Theory. What are elements?

Describe Chemical Energy; Chemical Affinity. What is chemistry? Discriminate carefully, with illustrations, between molecules and atoms. Do atoms exist uncombined with other atoms? How is it in the case of elementary substances? Instance molecules that contain one atom; two atoms; four atoms. Compare the molecules of gases, liquids, and solids, as regards separation. Explain and illustrate the principle on which atoms and molecules are kept apart. What is Porosity? Can you mention any substance which has visible pores? Distinguish between these and molecular pores. What is the result of mixing equal volumes of alcohol and water? Of mixing salt and water? How does the volume of the liquid of the solution often compare with the original volume plus that of the solid?

If two volumes of hydrogen were mixed with one of oxygen and exploded, the substance produced would be water. If the explosion were made over mercury in such a way that the water could be collected, it would be found that the amount of water from a litre (see page 540) of the gases would be but a few

drops. How does this illustrate porosity? How is the foam on a glass of soda-water due to this same property of matter? How may the mass in a tumbler filled with buckshot be increased? Why? Would a tumbler filled with melted lead be more massive than if filled with shot? What does the familiar process of filtering or straining liquids prove? Express your idea of the extreme minuteness of molecules and atoms.

MEASUREMENT OF MASS, FORCE, ENERGY, AND WORK.

MASS MEASUREMENT.

Equal Masses.—In the arrangement of a system of measurement of mass, force, energy, etc., we must begin with a definition of what constitutes *equal* masses. Two masses are said to be equal when the same force, acting upon them separately, will produce in them equal accelerations.

We have, then, first to show some way by which we can actually measure off equal masses, in accordance with this definition; secondly, to explain how we can produce graded sets of masses (usually called sets of weights); and, thirdly, to state the units of mass generally employed. How masses are actually measured in practice by the process called weighing will be described in the section on forces, as it is done by using of the force of weight.

First, then, how can we apply exactly the same force to make it act on different portions of matter in such a way that we can measure the accelerations produced? Weight affords us the easiest means of doing so; for we may assume that

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NOTE.—Hereafter we shall speak of acceleration, change of direction of motion, distortion of bodies by stretching or bending, etc., as produced by the action of force, just as if force, and not the energy producing it, were the real cause. This is more convenient, and is almost universally employed, but the pupil will find himself freed from much confusion of thought if he will always bear in mind that the real cause is in all cases energy, and that force is never anything but a condition of matter incidental to the action of energy.

experience has shown us that the weight of a given body at the same part of the earth's surface is constant, unless some matter is either added to or taken away from the body.

Obtain a board (A B, Fig. 21) 8 feet or more long, 9 to 12 inches wide, and 1½ to 2 inches thick. One surface must be very smooth, and must always be a perfect plane. Mark across the board black lines, one eighth of an inch wide, at equal intervals of 10 inches throughout its length. Construct a strong cart about 10 inches long by 6 inches broad. Its wheels may be of wood, and about 4 inches in diameter; but brass or iron is preferable. They must be carefully turned in a lathe into true circles. The axles must be of brass or iron, and the wheels well centered. At one end of the board A B fasten a grooved pulley D, 4 or 5 inches in diameter. This must also turn very freely, and its top at D should be at the same height above the board as the point of attachment to the cart. A cord is run from E over D to a strong pan W. The board must be laid horizontally on a table, or on brackets 6 feet or more above the floor, to give room for the descent of W.

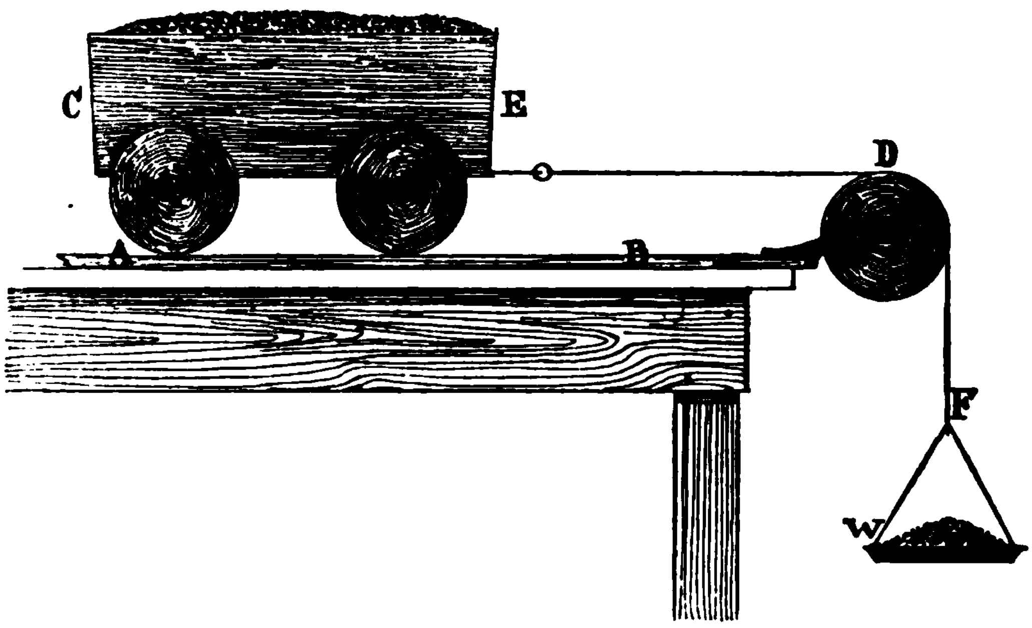

FIG. 21.—LOADED WAGON, WITH PULLEY AND SCALE PAN.

We are to observe the accelerations produced in the loaded cart by a weight at W. To do this properly, it is necessary that all resistances, of which friction is the chief, should be reduced as much as possible. Oil the axles. Then remove the cord and pan by unhooking at E. Give the cart a gentle push toward D. It will roll a short distance, and then stop because of friction. Raise the end A of the board considerably, and push again. The cart will roll down the board with accelerated motion. Now lower A gradually, pushing the cart from time to time. By repeated trials a height will be found for A which will just keep the cart in very slow motion when started, and will not increase its speed. Leave the board in this position, for here the weight of the

cart just about neutralizes the resistance of friction, and that source of error is almost removed.

Now hook the cord on at E, and hang it over D. Put into the car some sand or shot, and a small amount of the same into the pan. We shall then have a force at W equal to the sum of the weights of the sand and pan (we may neglect that of the cord). This force will be always the same so long as no more sand is put in and none taken out. We have, therefore, a constant force which we will call W, and which tends to set in motion all the movable mass, viz., itself plus the mass of the cart and load.

Some device is needed to stop the cart when in rapid motion. Tie up in a bag two or three pounds of sand or shot. Fasten to this a strong cord about two feet shorter than the board, and tie the cord to the rear end of the cart. Place the sand-bag upon the board at the end away from the pulley, and leave the cord loosely coiled or folded back and forth on the board. Place also a box or other shelf at such a distance below the pan W that the pan will rest upon it when the cart is two feet or less from D. If, then, the cart starts from the rear end of the board, it will move along freely till it reaches a point where E is one or two feet from D. Then W will cease pulling, because resting on the shelf, and the sand-bag will begin to act as a drag or brake to stop the cart. If a few inches of rubber tubing or coiled steel or brass spring be put in between the cart and sand-bag, the cart will be less violently jerked.

For class illustration, upright rods may be inserted at the black lines on the board, and an upright pointer attached to the cart.

The Motion produced by the Constant Force is accelerated.—Let us now see what the character of the motion is when the constant force W is moving the mass of the loaded cart and itself. Pull the cart back till the pointer stands at a line near the starting end of A B. Let it go, and observe its motion. You will see that it moves slowly at first, and then continually faster and faster—that is, the motion is accelerated. To perceive this clearly, count as follows: At the instant of releasing the cart, say zero; at the instant it crosses the next line (having passed over one space on the board), count one; at the third line, count two; and so on. You will perceive in this way that each space is passed over in a less time than the preceding one,

and that the motion is thus accelerated. If the friction were constant, and you had means of observing accurately, you would find that the motion was *uniformly* accelerated.

The Rate of Acceleration by the same Force is less as the Mass moved is greater.—Take out some of the sand from the cart, and repeat the experiment. The cart will be found to move faster. If more load is put in, it will move more slowly. Thus, if we lessen the mass, the same force produces a greater acceleration; if we increase the mass, it produces a less acceleration.

To measure the rate of acceleration, which is desirable for some later experiments, make a pendulum by hanging any heavy body with a cord from any firm support, as in No. 9, page 60. The shorter the string, the faster the pendulum will swing. The time occupied by the cart in passing from a mark near the end A of the board to one near the end B can be observed by noting the number of swings of the pendulum. This can be best done by varying the length of the pendulum until it makes some whole number of swings while the cart is passing from A to B. By the laws of uniformly accelerated motion, the cart is equally accelerated when it passes over the space A B in equal times. If the cart passes from A to B in half a given portion of time, the acceleration will be four times as great (see page 20). If it travels in one third the time, the acceleration will be nine times as great; and so on.

To measure off Equal Masses of the same or of Different Kinds of Matter.—Leaving W unchanged, remove all the sand from the cart, and lay it carefully aside to be weighed in the next experiment. Put in its place some other kind of matter, for example, shot. The cart will now move faster or more slowly than with the sand in the last experiment, showing that the whole mass moved is either less or greater than before.

By adding or removing shot, a quantity will at length be found with which the cart will move from A to B in exactly the same time as with the sand. Hence the rate of acceleration is the same—the same force (weight of W) is producing the same acceleration on two different collections of matter. We have, therefore, two masses, viz. (cart + sand + mass at W) in one case, and (cart + shot + mass at W) in the

other, on which the same force produces equal accelerations. Therefore, these two masses are equal.

Further, as the mass of the cart and of W are the same in both cases, the mass of the shot must be equal to the mass of the sand. Thus we have a means of determining by a simple experiment whether two masses are equal, as well as of constructing equal masses.

The Weights of Equal Masses stretch a spring by equal amounts, or counterpoise each other on a balance.

Put the sand of the last experiment upon a spring-balance. The spring will be stretched by a certain amount. Replace the sand by the shot, and the spring will be equally stretched. The same result will be reached whatever kind of matter the equal masses are composed of, and however massive they may be.*

Instead of using a spring-balance, the sand and shot might be put in opposite pans of an equal-arm balance, and would then be found to counterpoise each other.

The last two experiments can be made more satisfactory, although really no more accurate, by reversing their order. To do so, measure off by the spring-balance quantities of sand and shot which will stretch the spring equally. Put the sand into the cart and time its passage from A to B, using a suitable weight at W. Replace the sand by the shot, and time again. The time will be found the same. This proves that masses whose weights stretch the spring equally are equal masses. As this would be found true, however massive the equal portions and of whatever kind of matter, the converse proposition that equal masses stretch the same spring equally would be proved.

Graded Sets of Masses.—The principle just explained enables us to construct a graded set of standard masses. If we take the sand of the foregoing experiment, or *any mass of any substance*, and divide it into two portions which stretch a spring equally or which counterpoise on an equal-arm balance, the mass of each portion must be just half that of the original mass. Similarly we may divide the original mass or its parts into any desired number—3, 5, 10—of

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* It may at first sight appear that we have thus proved that equal masses have equal weights. This proposition will be shown to be true, but we can not prove it until after we have defined equal forces. As yet we have not shown that the spring can not be equally stretched by unequal forces of different kinds.

equal masses, which will be $\frac{1}{3}$, $\frac{1}{5}$, $\frac{1}{10}$ of the original mass; or we can produce masses two, three, and ten times as great as the original. It is in this way that the graded sets of masses are originally arrived at. Such sets of masses are commonly spoken of as "sets of weights," as they are used in the process called weighing. This process depends upon principles respecting the equality and measurement of forces, and will, therefore, be described after they are discussed (page 86).

In order to enable men all over the world and at all times to make measurements of mass which will be comparable with one another, it is essential that they should use as a basis of their measurements the same quantity of matter. This is accomplished by having a standard mass in terms of which all masses are expressed.

Standard Mass.—As a standard quantity of matter with which to compare all other masses, we may adopt any given piece of matter which we choose. For instance, we may select a particular orange as our standard quantity. We should then say that any object having twice as much matter as the orange would have twice the standard mass, and so on; but the orange is perishable and would need to be replaced from time to time, while our design in fixing a standard is to have a mass for reference so that measurements of mass made by one person may be comparable with those made by another, and those made to-day may be comparable with those made a century hence. Therefore our standard mass must be as nearly imperishable and unchangeable as possible, and must be carefully preserved.

There are two fundamental standard masses to which all measurements in most civilized countries are referred. One is a piece of platinum carefully preserved by the French Government at Paris and called the "Kilogramme des Archives" (kilogramme of the archives). The other is a piece of platinum, in the office of the Exchequer at London, called the Standard Pound.

Very careful determinations have shown that the mass

of the standard kilogramme is 2·2046212 times the mass of the standard pound, so that the pound is equal to 0·45359265 kilogrammes.

Copies of these standards in platinum and in other metals—i. e., pieces having as nearly as possible the same mass as the standards, are in the possession of various governments and are made the legal standards of the various countries. The copies belonging to our Government are in the keeping of the United States Coast and Geodet'ic Survey at Washington, D. C. The original standards and these chief copies are used only occasionally in order to protect them from wear and accidental injury. Secondary copies made from them are in general use.

NOTE.—Platinum is used in these standards as being the least perishable and changeable of all the metals.

QUESTIONS.—What is mass? In measuring mass, force, energy, etc., what are we obliged to take as a starting-point? Define equal masses. Why can we not say equal forces instead of "the same force" in this definition? What is the readiest means of applying the same force at different times? Would any other force than weight lead to the same results if it were equally steady? How do we arrange to apply the same force successively to different masses in the cart experiment? In any case what is the total amount of matter to be moved in an experiment with the cart? What kind of motion does a constant force produce on a constant mass? How is this illustrated by the cart experiment? How does the rate of acceleration by the same force vary as the mass varies? How is this shown by the cart experiment? If the cart moves from one mark to the next in two seconds on one occasion and in one second on another, how great is the rate of acceleration in the second instance as compared with that in the first? Why?

How can equal masses be measured off by the cart experiment? Can a quantity of air and a quantity of lead have the same mass? After the construction of two or more equal masses by the cart, what important proposition is next proved? How can we construct equal masses by applying this proposition? How can we construct a graded set of masses? Why are sets of masses usually called sets of weights? What is the object in having a standard of mass? What is the chief quality necessary in such a standard? Name and describe the two chief standards in general use.

MEASUREMENT OF FORCES.

Equal Forces.—We must now learn how to measure forces—that is, how to compare the magnitude of one force with that of another. That action of energy which we call force is most naturally recognized (page 46) by the acceleration produced in free bodies, its amount may be measured

by the amount of acceleration it causes; but the acceleration produced by a given force has already been proved by experiment (page 80) to vary with the mass accelerated. Hence, in measuring forces, both the mass moved and the rate of acceleration must be taken into account. Let us start, then, with the following definition:

Forces are equal when they can produce equal accelerations upon the same or equal masses.

Equal Masses have Equal Weights.—We may apply this definition in connection with the cart experiment to prove the proposition that equal masses have equal weights.

Take several equal masses of any kind and of suitable amount. Prove that they are equal masses by ascertaining that they stretch the spring-balance equally, or that they counterpoise each other on the equal-arm balance. Put one of them into the pan at W. Load the cart until the weight at W produces a convenient acceleration. Time the passage from A to B as before. Remove the mass from the pan and put in another of the equal masses. Time again from A to B. Repeat with a third of the equal masses. The times will all be found equal; but the mass moved was equal in all cases, being the total mass of (cart + load + pan + mass in pan); therefore, by the definition of equal forces, the forces causing these equal accelerations must have been equal. What were the forces? The weight of the pan plus that of one of the equal masses. These total weights were then constant; but the weight of the pan was the same in each case; hence the weights of the equal masses must also have been equal. The same result would be found with any equal masses of whatever material. We may, therefore, conclude that at the same point on the earth's surface equal masses have equal weights.

We have thus a means of obtaining a force of any amount which we may desire, for the weight of two equal masses is thus proved to be twice that of one of the masses, and so on. For instance, if we desire to obtain a force of say 23·2 times that of the weight of one of the above masses, we have only to put together twenty-three and one fifth of the equal masses, and the weight of these will be the desired force. This gives us one easy and exact method of measur-

ing forces, for we have only to balance the forces to be measured against the weight of known masses. We must remember, however, that the weight of a given mass is not precisely the same at all parts of the earth's surface, as further stated on page 91.

While the experiments with the cart serve to illustrate roughly the law that equal masses have equal weights, yet for scientific purposes more exact proofs are necessary. These were first obtained by Newton through experiments with pendulums of different materials, and have since been verified in a great variety of ways.

Spring-Balance or Dynamometer, for Measurement of Forces.—The spring-balance is really an instrument for measuring forces, and is therefore called a dynamom′eter (*force-measurer*). One form of it, represented in Fig. 22, consists of a coiled or spiral spring, whose upper end is secured to the top of the apparatus, and whose lower end is attached to a straight rod carrying an index or pointer and having a hook at the bottom. If an object is hung upon the hook, its weight stretches the spring by a certain amount and holds the index steadily at some point along the scale, thus indicating the weight of the object.

FIG. 22. SPRING-BALANCE.

This scale is originally graduated by hanging upon the hook various known masses and marking their weights opposite the index. For instance, a mass of one pound is suspended and a mark made opposite the index. A mass of two pounds is then attached and another mark made, and so on; or kilogrammes may be used instead of pounds if the metric system of weights is preferred (see page 540).

If an object of unknown weight is hung on the hook, the index will stand at a certain position. Suppose this happens to be half-way between the three and the four pound mark. Then the weight of the object is equal to *the*

weight of a mass of 3·5 pounds, or, we may say, for brevity, its weight is 3·5 pounds. If any other force than a weight stretches the spring, then the index-reading gives the amount of that force. For instance, suppose that the balance were horizontal, and that a piece of iron were fastened to the hook with a magnet beyond it, and that their mutual attraction stretched the spring so that the index stood at the four pounds mark. Then we should know that the force of attraction between the iron and the magnet was equal to the weight of a mass of four pounds. Similarly we might measure any kind of constant force.*

Weights by Equal-Arm Balance.—For reasons which will be explained when the instrument is described, the equal-arm balance swings evenly when the weights of the objects in the two pans are equal. The usual method of weighing is to place the object to be weighed in one pan, and in the other to put masses from a graded set, changing these until the balance swings equally on each side of its position of rest. The weight of the object is then equal to the weight of the known masses in the other pan.

It is sometimes possible, but seldom convenient, to arrange such a balance for measuring other forces than weight.

The process of weighing is one capable of great precision and delicacy. Equal-arm balances have been constructed which show a difference of one ten-millionth part of the whole load on the pan.

Measurement of Masses by the Equal-Arm Balance and by the Spring-Balance.—As equal masses have equal weights, it is evident that the equal-arm balance enables us to measure masses easily in terms of a graded set

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* Observe that the pound, like the kilogramme, originally and properly denotes a certain *mass* of matter, but that for convenience in speaking of weights we say "the weight of a pound," or of a kilogramme, instead of using the correct but longer phrases, "the weight of a pound of matter," "the weight of a pound-mass," etc. So in the case of other forces, we speak of "a force of one pound," meaning "a force equal to the weight of a pound of matter." It is important to keep this in mind to avoid confusion.

of masses. When the weights in the two pans are equal, the masses, of course, are equal.

For instance, if, to balance a certain object, it is necessary to use a two-pound, a one-pound, and a half-pound mass in the other pan, the object has a weight equal to that of a mass of 3·5 pounds. Its mass is thus shown to be 3·5 times the mass of a standard pound.

To produce the same Acceleration on Different Masses, the Force must be proportional to the Mass moved.—Put on the cart a small load, and on W enough weight to produce a convenient acceleration. Time the passage from A to B. Weigh W, also the cart and contents together with W.

Double the force at W and add to the load upon C until it goes from A to B in just the same time as before, and hence has the same acceleration. Weigh C and W together again. The weight, and therefore the mass, will be found to be twice as great as before.

Double the force at W and double the total mass, and observe that the cart passes from A to B in the same time as before. Make W and the total mass five times as great as at first, and notice that the cart still travels from A to B in the same time. Hence, to produce the same acceleration on different masses the force must be proportional to the mass moved.

Acceleration of Constant Mass proportional to the Force.—Load the cart rather heavily. Put on a load at W which will give a slow motion. Time the movement from A to B as before. Next weigh W—i. e., pan and contents. Take from the load of C a weight equal to three times W, and put it into the pan in addition to the former load. We know then that we have made the force at W four times as great, but have not changed the whole mass to be moved. Time the motion from A to B again. You will find the space is traversed in half the time.

What was the acceleration here? From the laws of accelerated motion (page 20), we know that when the time of passing over the

same space is one half as great, the acceleration is four times as great. If we make the force (weight at W) nine times as great as at first, the time will be found to be one third, and therefore the acceleration to be nine times as great, and so on.

Thus the acceleration of the same mass is four times as great when the force is four times as great, and nine times, when the force is nine times—that is, with a constant mass, the acceleration is directly proportional to the force applied.

A Constant Force is proportional to the Product of the Mass into the Acceleration produced by it upon that Mass.—The statements of the two foregoing paragraphs may be combined in one, viz., that to produce in a given mass a given acceleration, the force must be proportional to the product of the mass into the acceleration.

For instance, suppose that we begin with a given mass and force. This force will produce a certain acceleration. If we double the mass, twice the force will be necessary to produce the same acceleration; but if we desire to increase the acceleration, say to treble it, we must also treble the force. Hence, to give the double mass a trebled acceleration, we must apply six times the first force. To make a mass five times as great as the given mass move with seven times the acceleration, would require a force of $5 \times 7 = 35$ times the first, and so on.

Conversely, if a body is seen to be moving with a uniform acceleration, we know that it must be under a uniform force proportional to the product of its mass into its acceleration.

Newton's Second Law of Motion.—The universal experience in regard to the direction and amount of effect of forces is stated in Newton's second law of motion.

"Change of Motion is proportional to the impressed force, and takes place in the direction of the straight line in which the force acts."

In this law, "change of motion" means the product of the mass into the acceleration produced by the action of the force in question upon a free body of the given mass.

Units.—When we measure a quantity of any kind, we express it in terms of a unit—that is, a definite quantity—of

the same kind. If, for instance, we say that the side of a room is eighteen feet long, we mean that its length is eighteen times the length which we call a foot. If we say that two towns are 23·54 miles apart, we mean that their distance apart is twenty-three and $\frac{54}{100}$ times the distance which we call a mile. Here the foot was the unit of distance in the first case, and the mile the unit of distance in the second. We might have expressed either distance in inches, yards, rods, metres, kilometres, or any other unit which we chose to use. Thus the choice of a unit is wholly arbitrary. We can select a unit of such size as to be convenient for the purpose in hand, and there may be, and usually are, many different sized units of the same kind, as just shown for units of length.

But it should be remembered that units for measuring the same kind of quantity are all and always of the same kind as that quantity, and are merely arbitrarily chosen amounts of that quantity. They differ only in size. Thus, the inch, foot, metre, mile, etc., are a few of the various units of length. They are all the same kind of thing, viz., distances. They differ only in size. Similarly, the quart, litre, gallon, hogshead, gill, etc., are units of capacity; they differ in nothing but magnitude. This is true, however complicated the nature of the quantity measured.

The Idea of Standards must be kept distinct from that of units. A standard yard is merely a metallic bar with lines ruled upon it, whose distance apart at a stated temperature is defined by law to be one yard. The yard is used as a unit of length. It is not, however, the only unit of length, and in fact is merely a fixed distance by reference to which various other units of length can be defined and reproduced. Thus, the foot is equal to one third of that distance, the mile is equal to 5,280 such feet, etc.

The standard metre is a bar of platinum preserved by the French Government at Paris, having lines ruled

upon it whose distance apart, at a stated temperature, is defined by law to be one metre. This distance is about 3·4 inches longer than the yard. The metre is exactly 39·3702 inches.

We may use any multiple or submultiple of these standard distances which we choose as units in any particular case, or indeed any other distances; but, in order that our measurements should convey an exact idea to others, they must be expressed in units whose relation to the standards is accurately known.

The standard pound and the standard kilogramme are, as has been stated, standard masses; but neither is commonly used as the *unit* of mass. For reasons which will appear, the units of mass actually employed are either larger or smaller than these standards, but bear a perfectly definite and known ratio to them. In the following paragraphs, the scientific units will be defined and described first. The engineering and other units will be summarized later.

Unit of Length.—In scientific work the unit of length generally employed is the centimetre, viz., the one-hundredth part of the standard metre.

The Unit of Time commonly adopted is the second.

The Unit of Mass employed in almost all scientific work is the mass of one gramme, or the one-thousandth part of the mass of the standard kilogramme.

Instrument-makers supply graded sets of masses. These may contain any amounts desired. A convenient set contains pieces of one kilogramme, and of 500, 200, 200, 100, 50, 20, 20, 10, 5, 2, 2, 1 grammes, and so on, for such decimals as are desired.

The system of units based on the centimetre, gramme, and second, is called the centimetre-gramme-second system, or the C. G. S. System. In computations where this system is to be employed, all quantities of length, mass, or time, must be reduced to, and expressed in, centimetres, grammes, or seconds, before being used. A similar statement holds good for any other system.

The Unit of Force, in all systems, is a force which will produce unit acceleration upon unit mass. In the C. G. S. system, the unit acceleration is one centimetre per second. The unit of force—C. G. S.—is then a force which can produce an acceleration of one centimetre per second on a mass of one gramme. This unit of force is called the Dyne.

Any constant force F, which is producing in a mass of M grammes an acceleration of a centimetres per second, must be equal to $M \times a$ dynes (i. e., $F = Ma$); for to produce on a mass of M grammes an acceleration of one centimetre per second, would require M dynes. To produce on the same mass an acceleration of a centimetres per second would require a times this force—i. e., Ma dynes—or, in any system of units, to produce an acceleration of a units on a mass of M units would require a force of Ma units.

Example.—Suppose that we observe a body moving with a uniform acceleration of 250 centimetres per second, and find by the balance that the body's mass is 400 grammes. What is the amount of the force producing the acceleration? $F = Ma = 100{,}000$ dynes.

To obtain an idea of how large this unit of force is as compared with that very familiar force, the weight of some standard body, we may take a body whose mass is one gramme and let it drop from a height. It will be accelerated by a constant force, its weight, and will therefore fall with a uniformly accelerated motion. By exact experiment, that acceleration is found to be in the latitude of Boston, and at the level of the sea, about 980·4 centimetres per second. The force with which the mass of one gramme is drawn toward the earth—i. e., the weight of a gramme—is then much greater than one dyne. A dyne would have given it an acceleration of only one centimetre per second, but it received an acceleration of 980·4 centimetres per second. We have proved that the force is proportional to the acceleration. Hence this force must have been equal to 980·4 dynes; or, to state it in another way, $F = Ma$. $M = 1$ gramme, $a = 980{\cdot}4$ centimetres per second, $F = 1 \times 980{\cdot}4 = 980{\cdot}4$ dynes. The weight of the gramme is, therefore, 980·4 dynes in latitude 42° at sea-level.

We thus have an easy way of producing the dyne at any time. Take the mass of $\frac{1}{980}$th of a gramme. This mass will be attracted toward the earth by a force of exactly one dyne. You will see from this also that a body whose mass, as found by the balance, is M grammes, weighs $980 \times M$ dynes. For instance, a body whose mass is 300 grammes weighs—i. e., is attracted to the earth by a force of—$980 \times 300 = 294{,}000$ dynes. The dyne is thus a very small force. It is convenient for much scientific work, especially in electricity and magnetism, but is not so for engineering work where large forces are to be dealt with. A more convenient unit for such work is described later.

It is a fact of importance that if the mass of a gramme is dropped near the sea-level at the equator, it will have an acceleration of only 978·1 centimetres per second; at latitude 45° sea-level, the acceleration would be 980·6 centimetres per second; at the pole, it would be 983·1 centimetres per second. The letter g is commonly used to denote the acceleration due to weight. This acceleration is found to be very slightly less above the sea-level; for example, at 45° sea-level it is 980·6, but at 1,000 feet above the sea it is about 980·5. As has been shown, it is due to the weight of the body. If, therefore, the same body be taken to various places, its acceleration will be different, and its weight will be different in the same proportion. Thus, the weight of the same or an equal mass at the equator is about $\frac{1}{190}$th part less than that at the poles. In general, the weight in dynes of a gramme at any place where the acceleration of gravity is g, will be g dynes.

To measure the Force with which a body is attracted to the earth—i. e., to ascertain its weight—we may put it into one pan of an *equal-arm balance* (page 163) and place in the other pan standard masses until we have just enough to counterbalance it. Thus the weight of the masses just equals that of the body. Suppose we count up the standard masses used, and find them to be 340 grammes. We know then two things: first, that the mass of the body is 340 grammes; second, that the weight of the body is $340 \times g$ dynes; and, knowing g to be 980·4 centimetres per second, we know that the weight is $340 \times 980 = 333{,}200$ dynes.

It is confusing to students when they first notice that all bodies, whatever their mass, fall to the earth with equal acceleration; but it is easily understood by considering that the weight is proportional to

the mass, so that, although the force causing the heavier body to fall is greater, the mass to be accelerated is greater in the same proportion. Hence the acceleration must be the same. Prove this by dropping, side by side, objects of equal and different weights.

The spring-balance has been described as a convenient instrument for measuring forces. In order that it may measure them directly in terms of the C. G. S. unit, it should be graduated by hanging upon it masses of $\frac{1}{980}$, $\frac{2}{980}$, etc., grammes, as the weights of these masses are 1 dyne, 2 dynes, etc.

But as any unit of force differs from the dyne only in amount, we may use a balance graduated in any unit and reduce to dynes by multiplying by a suitable factor. Thus, the weight of the standard pound at London is equal to about 445,000 dynes. If a force were measured by a spring-balance graduated at London in pounds and found to be 2·1 pounds, the force would be about 934,500 dynes.

Momentum.—If a body, of mass M, is moving with a velocity V, the product MV of its mass by its velocity is called the Momentum of the body.

The momentum is equal to the product Ft of the force into the time; or $MV = Ft$. Therefore, $F = MV \div t$. For $V = at$ and $F = Ma$ $\therefore$ $F = Mv \div t$ or $Mv = Ft$.

EXAMPLE.—If a body with a mass of 10 grammes is moving with a velocity of 5 centimetres per second, then its momentum would be $MV = 10 \times 5 = 50$ units. This momentum might have been produced by any uniform force F acting for a suitable time t. If it had been produced in $t = 2$ seconds, then the force must have been $F = MV \div t = 50 \div 2 = 25$ dynes; if in a time of 0·002 second, then the force must have been $F = 50 \div {\cdot}002 = 25{,}000$ dynes; if it had been produced by a force of 5 dynes, the time during which the force must have acted would have been $t = MV \div F = 50 \div 5 = 10$ seconds.

If the force causing the momentum is not constant, then the force computed by the expression above would be the *average* value of the force during the time t. The average value is that amount which we should find if we could divide the time into extremely small intervals, and could find the amount of the force at the middle of each interval, and should then take the average of all these values—that is, add them all together and divide the sum by their number.

Impulse.—The product Ft of the force into the duration of its action is called its Impulse. It has just been

shown that $Ft = MV$, hence we may say that the impulse of a force is measured by the momentum produced. There are many cases in which forces act for short times only, as when the gases caused by the burning powder in a gun are forcing out the bullet, or the bowstring is speeding the arrow, or one elastic body strikes another, as when a ball is struck by a bat. In such cases, the force is not constant but varies rapidly, besides being of very brief duration. Here we can not usually know either t or F, but only MV, so that the amount of the impulse is found from MV.

Time required to set Matter in Motion.—However large the force acting, and however small the mass acted upon, some time is required to impart any velocity. This time is expressed by the equation $t = \frac{MV}{F}$. If M and V are very small and F is very large, t will necessarily be small, but can never be zero. To make t zero would require an infinite force F, and anything infinite is beyond our physical experience and beyond our powers of conception.

Questions.—Define equal forces. Prove that equal masses have equal weights. Does this fact require proof? How does this give us a means of obtaining any desired amount of force? Describe the spring-balance. Why is it called a dynamometer? How is the scale of the spring-balance originally graduated? How would you use a spring-balance to measure the weight of a body? How would you use it to measure some force not in a vertical direction? In such a case, would you have to make any allowance for the effect of the weight of the parts of the balance itself?

Is the standard pound a mass or a weight? What is weight? When we speak of a force of one pound, what do we mean? Describe the process of obtaining the weight of an object by an equal-arm balance. Is it a process capable of accuracy? How does the process of measuring the mass of an object by a balance differ from that of measuring its weight? By an experiment, 2·5 pounds are found necessary to balance an object; state in full what the weight of the object is and what its mass is. Why and how much is the spring-balance in error when used at other places than that for which it is graduated?

If one mass is four times another, how many times as much force is necessary to produce upon it a given acceleration? Define acceleration. If to a given body you apply successively forces of 2 and 4, what will be the relative accelerations? What is the relation between the force and the acceleration produced by it upon any mass? Is this true of any but a free body? State Newton's second law of motion.

What is meant by a unit? What determines the size of unit selected for a given purpose? In what respect do different units of the same kind differ? Do they differ in any other respect? What is the scientific unit of length? Of time? Of mass? What is the C. G. S. system? In what units must lengths be expressed before being used in computations? Masses? Times? Why? Define the unit of force in general. What is the C. G. S. unit of force called? Define it. Show how in these units $F = Ma$.

A body is moving with an acceleration of 10 centimetres per second. Its mass is found by the balance to be 30 grammes. What is the force acting?

A body of a mass of 20 grammes is moving under a constant force of 40 dynes. What is its acceleration?

An object under a force of 50 dynes is receiving an acceleration of 5 centimetres per second. What is its mass?

Show what the weight of a gramme is when expressed in dynes at a place where the acceleration of gravity is 980 centimetres per second. How does this enable us to obtain a force of any desired number of dynes at any place?

What is the weight in dynes of an object whose mass is 2 kilogrammes at a place where $g = 981$ centimetres per second?

Why do all bodies, whatever their mass, tend to fall under gravity with equal acceleration? If a body were found by a spring-balance to have a weight of 3 pounds avoirdupois, what would be the force in dynes with which it is attracted to the earth?

Define momentum. Prove that the momentum produced by a constant force acting for a given time is equal to the product of the force into the time.

A body of a mass of 20 grammes is moving with a velocity of 30 centimetres per second. What is its momentum? If this momentum were produced in 5 seconds, how great must be the constant force required? If it had been produced by a constant force of 15 dynes, how long must that force have acted upon the body? Suppose the force had been variable and had produced this momentum in 10 seconds, what must have been the average amount of the force?

Define Impulse. Can a finite force produce motion in no time?

A ball whose mass is 100 grammes is struck by a bat and receives a velocity of 20 centimetres per second. What is the amount of the impulse?

MEASUREMENT OF ENERGY.

Matter and Motion are the only Essentials of Energy.—We have learned that matter can possess energy only by being in motion. We know also that for an onward-moving body the energy is greater as the mass and the velocity are greater. This has been shown by the experiments with the rolling balls, and is illustrated in every-day experience. The energy of a body, then, depends on its mass and its velocity.

If any portion of matter M is moving with a velocity V along its path at any instant, then its energy E at that in-

stant is equal to $\frac{1}{2}MV^2$—that is, to one half the product of its mass by the square of its velocity.

The Unit of Energy in the C. G. S. system is the Erg.

Thus a mass of 40 grammes moving with a velocity of 10 centimetres a second would have an energy of $\frac{1}{2} \times 40 \times 10^2 = 2{,}000$ ergs.

Energy of Rotation.—A body may be rotating, but yet have no onward motion. In such a case each particle of the body possesses at any given instant a perfectly definite velocity, and therefore an amount of energy which would be denoted by $\frac{1}{2}MV^2$, where M is the mass and V the velocity of the particle. If we take the sum of all these quantities for the whole body, that sum will represent the total energy of rotation of the body. Rotation and onward motion can, of course, exist at the same time, so that a body may simultaneously possess energy from both motions.

The heavy *fly-wheel* of an engine in motion possesses an immense energy of rotation. Slowing down the speed of the wheel implies that a large amount of energy is taken from it, and this requires some time. Starting it again similarly requires energy and time. The fly-wheel, therefore, is a great help toward keeping the speed of the engine uniform. Think of the enormous energy of rotation of the earth or of the sun on its axis!

MEASUREMENT OF WORK.

Work is only a name for the process of transfer or transformation of energy.* It must, therefore, be expressed in the same unit as energy—that is, in ergs. Thus, if a body has imparted to it an amount of energy equal to 100 ergs, then the amount of work done upon it in imparting that energy will also be 100 ergs; and the amount of work which the body can do in giving up that energy will be 100 ergs.

* For the sake of brevity and convenience, we use the expression "amount of work done," or simply "work done," instead of "amount of energy changed in place or form." Remember that, when we speak of measuring the amount of work done, we mean measuring the amount of energy changed.

In many cases where the energy is transformed when the work is done, it is impossible to measure directly either the amount of energy given up by the body doing the work, or the amount received by the body upon which the work is done. For instance, if you raise a heavy body from the ground to a table, you expend muscular energy and produce potential energy. Now, it is not practicable to measure the muscular energy directly nor the energy which produces the condition which we call potential energy; but we have, nevertheless, a means of finding how much energy is transformed, as will now be shown.

Work against or by a Constant Force.—If a body is moved through a distance s against or by a constant force F, the amount of work done is equal to the product of the force into the distance—it may be expressed by $W = Fs$.

EXAMPLES.—A body weighing 50 dynes is raised vertically through 100 centimetres against gravity. How much work is done? $W = Fs = 50 \times 100 = 5{,}000$ ergs.

The same body falls freely through the same distance. How much work is done? $W = Fs = 50 \times 100 = 5{,}000$ ergs.

A body whose mass is 40 grammes falls freely through 10 centimetres at a place where $g = 980$ cm. sec.; how much work is done upon it by gravity? Its weight is $40 \times 980 = 39{,}200$ dynes. The work done is therefore $W = Fs = 39{,}200 \times 10 = 392{,}000$ ergs.

How much energy would it possess at the end of the fall? 392,000 ergs. Why?

Compute the energy from its acquired velocity. $E = \frac{1}{2}MV^2$. $M =$ 40 grammes. By the laws of accelerated motion, $V^2 = 2gs = 2 \times 980 \times 10 = 19{,}600$ cm. sec. Therefore, $E = \frac{1}{2} \times 40 \times 19{,}600 = 392{,}000$ ergs. This result is necessarily the same as that obtained by the other method, for the two formulæ Fs and $\frac{1}{2}MV^2$ must, of course, be equivalent.

How much work must be done to stop this body? 392,000 ergs.

How much to keep it moving with the acquired velocity? None, if there is no resistance to motion. How high would it rise if thrown vertically upward with this velocity?

The Amount of Work done is the same, whether the body is moved slowly or fast. For instance, in the first of the examples just given, the amount of work is obviously the same, however long or short the time occupied in raising the body may be. The amount of work depends only on F and s, and neither of these changes with the time. The

rate of work is different; but that is another thing, which will be separately considered.

The amount of work done is the same when the body moves freely and thus stores up the energy in itself as energy of onward motion, and when the body moves against resistance, transforming the energy or transferring it to other bodies. The "weight" of a clock will have done upon it by gravity the same amount of work in the course of its descent, whether it drops freely, or whether it descends in its usual slow manner, continually transferring the energy given it by gravity to the works of the clock where (in overcoming friction) this energy is transformed mostly into heat.

EXAMPLE.—A clock-weight has a mass of 40 grammes, and descends in a day through 10 centimetres. How much work is done upon it by gravity? Gravity does upon it 392,000 ergs of work (see preceding example) whether it descends slowly or falls freely.

The Amount of Potential Energy relatively to a given point, which belongs to a body because of its position and the force acting upon it, is equal to the energy which it would acquire in moving freely to that point, or to the work which would be done upon it by the force.

The potential energy of the clock-weight at its starting position relatively to a point 10 centimetres lower would be 392,000 ergs.

Similar computations apply to other kinds of force. Weight is selected for the examples because it is convenient and familiar.

QUESTIONS.—What is energy? How can matter possess energy? Is there more than one way in which matter can possess energy? What, then, do we mean by different forms of energy? What is potential energy? If a portion of matter of mass m has a velocity v, what is its energy? Relative to what does it possess that energy?

What is an erg? The air in an ordinary steam-car has a mass of about 300 pounds, or 140,000 grammes. Suppose the car to be moving at a rate of about 21 miles an hour, which is about 1,000 centimetres per second, what is the energy of the air relative to the ground? Suppose the car itself has a mass of 20 tons, what is the energy of the air as compared with that of the car?

A stone whose mass is 500 grammes is moving with a velocity of 1,960 centimetres per second. What is its energy?

How does a body in rotation possess energy? Relatively to what does it possess energy? Do its parts possess energy of onward motion relative to one another? Explain the action of a fly-wheel.

What is work? What is the C. G. S. unit of work? How much work must be done to set the air of the problem above into motion or to stop it, neglecting all losses? If any body is moved through a distance s against a constant force F, how much work is done? Give proof. In what direction must s be measured?

A body whose mass is 9,800 grammes is raised vertically 70 centimetres. How much work is done? What is the potential energy of the body at its new position as compared with its old? Where is the actual energy to which this so-called "potential energy" corresponds? If a body is moving with accelerated motion, what should we mean by saying that it was accumulating or storing up energy? If a body falls freely through 10 feet in one case, and in another descends only very slowly and uniformly through the same distance, does it take up from the energy of gravitation the same amount of energy in each case? Does "gravity" do the same amount of work in each case? What becomes of the energy in each case?

Suppose that instead of falling freely the same body falls with accelerated motion but at a less rate than if free, how much work is done by gravity? How much of the energy remains in the body? What becomes of the remainder?

OTHER CONVENIENT UNITS OF FORCE, ENERGY, AND WORK.

British Engineering Units.—The C. G. S. system of units is almost universally employed in modern scientific work; but for engineering and commercial purposes several other systems are in common use, partly for convenience, and partly from the continuance of long-established custom. The units of these various systems differ in no other respect than in magnitude.

The British engineering unit of length is the foot (one third of the standard yard); the unit of time is the second in general, but frequently the minute or hour, in dealing with long times; the unit of force is the weight of one pound—i. e., the force with which the quantity of matter called the standard pound is attracted to the earth.

British Engineering Unit of Mass.—Having thus defined the unit of force, we must next deduce the unit of mass. By definition (page 90), the unit force is a force which will produce a unit acceleration in a unit mass. In the British engineering system, a force equal to the weight of one pound would produce an acceleration of one foot per second when acting upon a unit mass. Let a mass of one

pound fall freely. The force accelerating it is the weight of one pound. The mass accelerated is the pound mass. What acceleration is produced? Exact experiments show that the acceleration will be very nearly 32·2 feet per second. The acceleration, then, is 32·2 times what the unit of force would produce in the unit of mass. *Hence the mass of one pound is only* $\frac{1}{32 \cdot 2}$ *part of a unit of mass, and the Unit of Mass in the British Engineering (B. E.) System must be the mass of 32·2 pounds—i. e., 32·2 times the mass contained in the standard pound.* This unit has no special name.

If, then, we find by the balance that an object contains a certain number of pounds of matter—e. g., 80·5 pounds—then its mass expressed in B. E. units of mass would be $80 \cdot 5 \div 32 \cdot 2 = 2 \cdot 5$ units.

Therefore, to find the number of B. E. units of mass in an object, ascertain by the balance the number of pounds mass it contains and divide by 32·2.

The B. E. unit of mass is simply a larger mass than the mass of the standard pound, just as the foot is a larger unit of length than the inch. As, then, we can express a distance of 54 inches by calling it $54 \div 12 = 4 \cdot 5$ feet, so we can express a mass of 70 pounds by calling it $70 \div 32 \cdot 2 = 2 \cdot 17$ B. E. units of mass.

The B. E. Unit of Work is the foot-pound—that is, the work done in moving an object through a distance of one foot by or against a force of one pound.

If a horse pulls a wagon 100 feet with a constant force of 75 pounds, how much work in B. E. units does he perform? $W = Fs = 75 \times 100 = 7{,}500$ foot-pounds.

The B. E. Unit of Energy is, of course, the same as that of work, viz., the foot-pound, as the amount of work is merely the amount of energy transferred or transformed.

Examples.—How much energy would a ton acquire in falling through 5 feet? $E = W = Fs = 2{,}000 \times 5 = 10{,}000$ foot-pounds. Or in falling 5 feet it would acquire a velocity (page 20) such that $V^2 = 2as$, and $a = 32 \cdot 2$ feet $\therefore V^2 = 2 \times 32 \cdot 2 \times 5 = 322$ feet per second. $\therefore E = \frac{1}{2} M V^2 = \frac{1}{2} \times \frac{2{,}000}{32 \cdot 2} \times 322 = 10{,}000$ foot-pounds.

What would be the energy of onward motion of a locomotive weighing 30 tons, if moving with a velocity of a mile a minute? $E = \frac{1}{2}MV^2$. $M = \frac{60,000}{32 \cdot 2} = 1,863$ B. E. units. $V = \frac{5,280}{60} = 88 \cdot 0$ feet per second. $\therefore E = \frac{1}{2} \times 1,863 \times 88^2 = 7,210,000$ foot-pounds. Therefore the engine must give out 7,210,000 foot-pounds of energy; or, in other words, must have done upon it 7,210,000 foot-pounds of work (by brakes, etc.) before it can stop. This would be equal to the work of raising 7,210,000 pounds, or 3,605 tons, one foot vertically against gravity, or one ton 3,605 feet (about three fourths of a mile)—or to the energy acquired by the engine itself in falling freely through $\frac{3,605}{30} = 120$ feet.

These results may give you a rough idea of the enormous energy of two trains coming into collision at high speed. But think how small this is compared with the energy of the earth moving in its orbit!

The French or Metric Engineering System is based on the metre, second, and kilogramme, instead of on the foot, second, and pound (see page 540).

The various units of mass, force, and energy, are related as follows for a place where $g = 981$ centimetres per second:

Mass of 1 kilogramme = 2·205 × mass of 1 pound.
Weight of 1 pound (avoirdupois) = 445,000 dynes.
" " 1 kilogramme = 981,000 dynes.
" " 1 kilogramme = weight of 2·205 pounds.
1 foot-pound = 13,560,000 ergs.
1 kilogrammetre = 98,100,000 ergs.
1 foot-pound = 0·13825 kilogrammetre.

Energy of other kinds than onward motion and potential energy, viz., heat-energy, energy of vibration, electrical energy, etc., may always be expressed in ergs, foot-pounds, or any chosen unit, and for some purposes are so expressed. Quantities of energy expressed in other units can be reduced to ergs or foot-pounds, if we know how many of the special units are equivalent to an erg or a foot-pound.

QUESTIONS.—On what account are the C. G. S. units not convenient for engineering work? What is engineering work? In what respect do other units differ from these? Is a unit anything but an arbitrarily chosen quantity? Can quantities of the same thing differ except in amount? Name the B. E. units of length, time, and force. Why should the B. E. unit of force be defined for a certain locality? What is the unit of mass in the B. E. system? What is the standard mass? Show how the unit of mass is deduced. Having given the mass of a body expressed in pounds, how would you find its mass expressed in B. E. units of mass? What is the mass in B. E. units of the air in the car of a

former example? What is the mass of the car? With how much force does the car press upon the rails?

In what unit must distances be expressed before being used for computation in the B. E. system? Times? Masses? What would happen if you neglected to express them in these units? What is the B. E. unit of work? Of energy? How much is the least work in B. E. units necessary to be done to lift a man whose mass is 150 pounds from the bottom to the top of the Washington Monument? How much would his potential energy due to gravitation be increased by that elevation? How much energy of onward motion would a man's body possess when it reached the earth falling from that height if not resisted by the air? What would be the energy in B. E. units of onward motion of the steam-car of a former problem? How much work in B. E. units must be done, neglecting losses, to start or stop the car? If the engine pulled with a constant force upon a train of five such cars, and was required to pull for one fifth of a mile before it could bring them from rest into motion at the stated speed, with how much force, B. E. units, must it pull, all friction and air resistance being neglected? How much work, B. E. units, must the engine do simply to get the mass of this train up to speed regardless of resistance?

RATE OF WORK.—ACTION AND REACTION.

Power.—Attention has been called to the fact that the amount of work in any given case is the same, whether the work is done rapidly or slowly. To lift a ten-pound weight 5 feet high requires 50 foot-pounds of work, whether the action occupies a fraction of a second or a century. But the *rate* at which work is done in the two cases would be very different. By rate of work (also called *activity*) is meant the amount of work done *per unit of time.*

The term POWER is used to denote the rate at which a source of energy is capable of doing work—i. e., of giving up energy. The relation between power and work is the same as that between velocity and motion—power being rate of work, velocity rate of motion, both rates being with respect to time.

The B. E. unit of power is the Horse-power. It is a rate of work of 550 foot-pounds per second, and very roughly represents the rate at which a horse can keep up continuous work. Thus, to raise a body weighing 550 pounds in one second through a vertical distance of one foot against gravity, would require work at the rate of one horse-power. This

is an arbitrary and not altogether convenient unit, but it is in very general use. Other units of rate of work are employed in electrical measurements.

An electric motor is required to run an elevator; what must be the nominal horse-power of the motor? To answer the question, we must know the rate at which work must be done upon the elevator. Suppose, then, that the elevator is required to rise at a speed of 30 feet per minute, when the total load is 2 tons, including the weight of the elevator. Then, neglecting friction, the rate of work must be $2 \times 2{,}000 \times \frac{30}{60} = 2{,}000$ foot-pounds per second. One horse-power is 550 foot-pounds per second; therefore, $\frac{2{,}000}{550} = 3{\cdot}64$ horse-power is the least horse-power of motor which will do the work. In practice, a motor of twice this capacity would be used, because the work required to be done against friction is usually very great.

Action and Reaction.—We have seen that two bodies, or at least two particles of matter, are necessary to the existence of a force, and that each possesses a tendency to acceleration. When we deal with the effect of the force upon that one of the bodies with which we happen to be concerned, regardless of the other, we speak of the effect as the *action* of the force. If we consider the effect of the force upon the other body, we speak of it as the *reaction* of the force. Whenever, then, there is a force, there must evidently be both action and reaction. This and some other facts are expressed by

Newton's Third Law of Motion.—"To every action there is always an equal and contrary reaction; or, action and reaction are equal and opposite."

Hold a book in your hand. The book and the earth tend to approach each other—that is, there is a force of attraction between them. The *action* of this force is the tendency of the book to be accelerated toward the earth, or its motion if it is allowed to fall. The *reaction* is the tendency of the earth to be accelerated toward the book, or its motion if allowed to move. Notice that the direction of motion of the earth and book would be t[illegible]ther—i. e., exactly opposite.

As shown on page 92, the product of the force into the time for which it acts, is equal to the momentum produced. In the case of action and reaction, the force is the same on both bodies concerned, and so long as it acts it affects both bodies. Hence the product of the force into the time must be equal for both, and the momentum generated in one must be equal to that of the other. That is, if m_1 and v_1 be the mass and velocity of one body, and m_2 and v_2 those of the other, then $m_1v_1 = m_2v_2$. This is true of all cases of action and reaction, of impact of elastic bodies, of attraction and repulsion of all kinds, etc.

The rate of action of a force is measured by the product *Ma* when acceleration occurs. Reaction would be measured in the same way.

The terms action and reaction are often applied, though incorrectly, to counterbalancing forces. For instance, when an object rests upon a table, the elasticity of the table is called into play, and the table exerts an upward force upon the object equal and opposite to its weight. But there are here two distinct forces, and the case is not one of action and reaction of a single force. The fact that a man can not lift himself by pulling at his boot-straps is an example of balanced forces, not of action and reaction. Would a huge bellows operated in the stern of a sail-boat produce a wind that would move the boat? Why?

Questions.—What is meant by rate of work? Power? Activity? What is a horse-power? Is it an amount of energy? Why? How does an amount of work differ from a rate of work? Can a force exist without affecting at least two bodies or particles of matter? Is force a tendency of one body to approach another, or of two bodies to approach each other? What is the distinction between action and reaction? Are they the effects of the same or of different forces? Give examples of them. State Newton's third law of motion.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Give an accurate explanation of the process of freeing a coat from dust by beating or shaking it.

A single tenth of a grain of musk, with but slight diminution of its weight, will diffuse a perceptible odor through a room for years. How does this illustrate divisibility?

How many cubic feet of water will be raised in an hour from a well 50 feet deep, if the rate of pumping be 15 horse-power? (Reckon one horse-power as equivalent to 8·8 cubic feet of water lifted 1 foot high per second, and the weight of a cubic foot of water at 62½ pounds.)

Prove that the injuries received in railway accidents are largely due to inertia.

The tendency of the ball being to retain the velocity imparted to it in the cannon, what takes place when it strikes the wall of a fort? Why?

A cannon-ball weighing 500 pounds is shot from a gun weighing 20 tons. What are the relative momenta? If the ball leaves the gun with a velocity of 2,000 feet per second, what is the velocity of recoil of the gun? Momentum of ball $= m_1 v_1 = \frac{500}{32 \cdot 2} \times 2{,}000 = 31{,}000$. The momentum ($m_2 v_2$) of the gun is the same. Hence its velocity $= \frac{31000}{m_2}$. Now, $m_2 = \frac{20 \times 2000}{32 \cdot 2} = 1240 \therefore v_2 = \frac{31000}{1240}$ feet per second.

If an engine is raising a mass of 20 tons at a rate of 2 feet a second, how many horse-power is the engine exerting? *Ans.* 145.

Suppose a bullet weighing one ounce and moving with a velocity of 1,000 feet a second is found to penetrate 2 inches into a plank. What must be the average amount of the force in B. E. units exerted by the bullet? We must first find E. One ounce $= \frac{1}{16}$ pound: therefore, mass of bullet in B. E. units $= \frac{1}{16} \div 32 \cdot 2 = 0 \cdot 00194$ B. E. units. $E = \frac{1}{2} \times \cdot 00194 \times 1000^2 = 970$ feet per pound. Now $s = 2$ in $= \frac{2}{12}$ ft. $= \frac{1}{6}$ ft. $\therefore F = \frac{E}{s} = \frac{970}{\frac{1}{6}} = 5820$ pounds.

A person weighing 130 pounds walks up a flight of stairs composed of 45 steps, each 8 inches high. How much work in B. E. units is the least that he can do? He must lift himself through 45×8 inches $= 30$ feet. He must, therefore, do $W = F s = 130 \times 30$ foot-pounds of work. What would be the potential energy of the person when half-way up?

A body is found by the balance to contain 150 pounds of matter. What is its mass in B. E. units? What is the mass of your body?

What is the mass of a ton of coal in B E. units?

A clock-weight has a mass of 2,000 grammes, and descends in a day through a weight of 10 centimetres. How much work is done upon it by gravity? $W = F s$ ($F = 2.000 \times 980$ dynes). *Ans.* 19,600,000 ergs.

With how much force in B. E. units does a locomotive weighing 30 tons press upon the rails?

We may make use of the cart experiment to determine the number of dynes in the weight of a gramme mass. Suppose we make the mass in W, including the pan, 100 grammes, and vary the mass in the cart until it moves over 180 centimetres in 3 seconds, and that we then find by the balance that the whole mass M of C and W is 2.450 grammes. What is the amount of the accelerating force, viz., the weight of 100 grammes? ($F = M a$.) *Ans.* 98,000 dynes. How many dynes in a one-gramme mass?

Suppose a steamer to be sailing at the rate of 12 miles an hour, and a ring to be tossed at the same rate of speed across the deck in a direction perpendicular to the course of the vessel; what is the velocity of the ring relatively to the surface of the sea?

Why does a base-ball player, in catching a flying ball, allow his hand, the instant the ball touches it, to be carried backward in the direction in which the ball was moving?

Explain the recoil of a gun against the shoulder.

ACTION OF FORCES.

COMPOSITION, EQUILIBRIUM, AND RESOLUTION OF FORCES.

Dynamics.—That branch of Physics which investigates the action of force and energy is called Dynam′ics (from a Greek verb meaning *to be able*). That part of Dynamics which deals with balanced forces is known as Stat′ics (from a Greek verb meaning *to cause to stand*); that part which treats of motion as produced by force, we call Kinet′ics. The sections on Energy and Force, which you have already studied, relate to Dynamics.

Composition of Forces.—Force, being a tendency to acceleration, and being measured by the acceleration produced on unit mass ($F = Ma$, page 91), may be represented by lines, in the same manner as velocities and motion.

Let A B, Fig. 23, represent in magnitude and direction the acceleration which a given force F would produce on a free unit mass; then A B also represents in magnitude and direction the force F itself, for this acceleration is equal to, and in the direction of, the force.

Suppose a second force, F_2, to act simultaneously with F_1 on a free unit mass, and that A C represents the magnitude and direction of the acceleration produced by F_2 alone. Then A C represents F_2. The resultant acceleration would be, as shown on page 24, the diagonal A D of the parallelogram; and this acceleration is that which would be produced by a single constant force acting in the direction A D, and represented in magnitude by the length of A D. The free body at A acted upon simultaneously by the two forces F_1 and F_2 (A B and A C) would move precisely as if acted upon by the single force R, equal to, and in the direction of, A D.

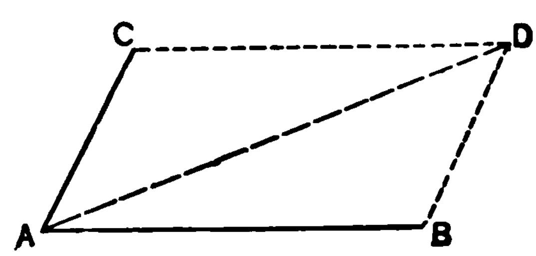


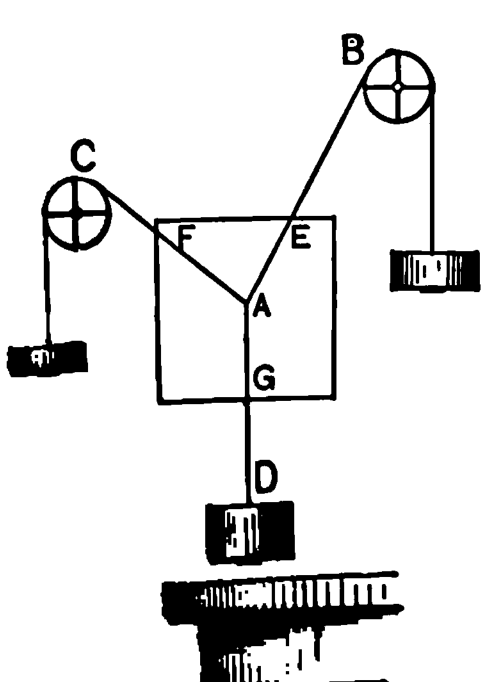
FIG. 23.

The equivalent single force found in this way is called the **Resultant Force**, or simply the Resultant.

EXAMPLE.—Two constant forces, $F_1 = 3$ pounds and $F_2 = 2$ pounds, act simultaneously on a body at an angle of 60° with each other. What is their resultant? Draw the straight line $A\ B$ (Fig. 23) of a length 3 units (take three quarters of an inch) to represent F_1. Through A draw $A\ C$ of a length 2 units (two quarters of an inch), and at an angle of 60° with $A\ B$, to represent F_2. Complete the parallelogram $A\ B\ D\ C$. Draw the diagonal $A\ D$. Measure its length. You will find it to be 3·6 quarters of an inch long. Then the combined action of F_1 and F_2 is equivalent to that of the resultant $R = AD = 3{\cdot}6$ pounds acting relatively to F_1 and F_2 in the direction $A\ D$.

Equilibrium of Forces.—The principle of the composition of forces shows that any number of forces acting simultaneously at a point are equivalent to a single resultant force. It has also been shown (page 48) that to counterbalance a single force—that is, to prevent acceleration—we must apply an equal and opposite force. Therefore, to counterbalance a set of two or more forces, acting at one point, there must be applied at that point a force equal and opposite to the resultant of the set.

Drive smooth wire nails into an upright board at B and C. Put upon them spools, or, better, large metallic or wooden pulleys. Knot together firmly three cords at A. Hang one cord over the pulley B, another over C, and let the third carry the weight D. Upon D suspend a weight of 5 pounds, on C a weight of 2·5 pounds, and on B a weight of 4 pounds. After a moment the apparatus will come to rest. A little jarring will reduce the error from friction. There will then be three forces at A acting along A B, A C, and A D respectively. As the point A is at rest, these forces are balanced, or, as it is said, are in Equilibrium (from Latin words meaning *equal balance*).



[illegible]

Let us see how the forces are related when this balance occurs. Put up behind A a large sheet of paper (or the apparatus [illegible] blackboard). Mark on the paper the direc- [illegible] points under A, E, F, and G. Take away the

paper, and draw lines through these points, and you will have lines A E, A F, A G, of Fig. 24. Select any two of these forces, say F and G. Lay off along A F a distance A *c* of 2·5 units (in Fig. 25 the unit is about three sixteenths of an inch) to represent the force F. Along A G lay off a distance of A *d* of 5 units to represent the force G. Complete the parallelogram and draw the diagonal A *f*. Measure A *f* carefully, and you will find it to be about 4 units—that is, the resultant of F and G is about 4 pounds and is in the direction A *f*. In other words, the two forces, acting in the lines A F and A G, are equivalent to a single force of about 4 pounds acting to pull A in the direction A *f*. To balance this single force would require, according to our previous statements, another force equal to it and opposite in direction. Consult the data, and you will see that the third force E is almost or exactly 4 pounds. Observe your diagram, and note that the resultant A *f* is almost or exactly in the same line with A E, but in the opposite direction.

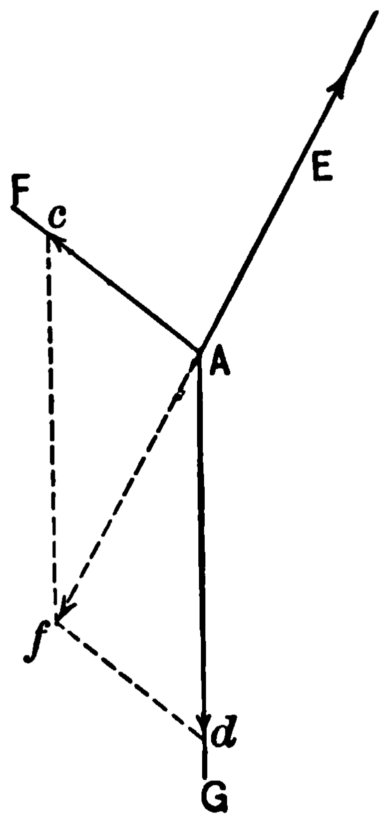


FIG. 25.

In your experiment, then, you had three forces in equilibrium, and you have shown that the resultant of two was equal and opposite to the third. If you had drawn the resultant of F and E, you would have found it equal and opposite to G, and so on. The previous statements have, therefore, been experimentally proved. They could be similarly demonstrated for several forces by using more pulleys, as in Fig. 26, and constructing resultants (see page 25). The student is advised to put together some such simple apparatus, and to experiment for himself.

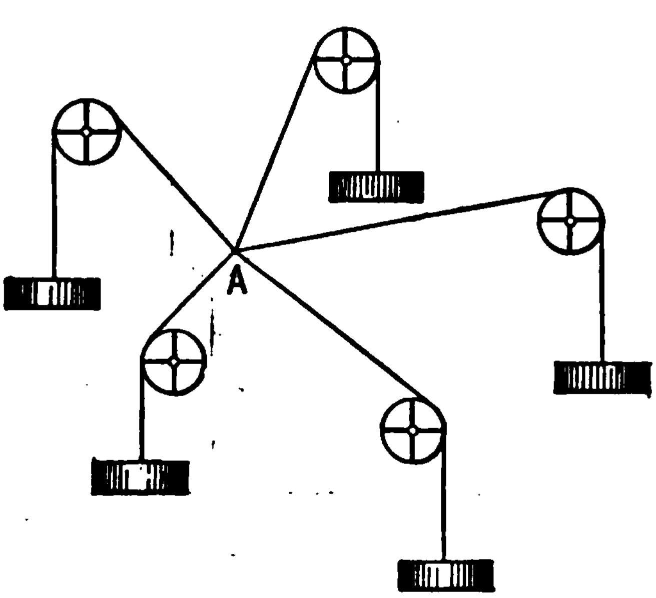


FIG. 26.—RESULTANT OF SEVERAL FORCES.

Resolution of Forces.—As we may resolve a given acceleration, velocity, etc., into components in any specified directions, so we may by the same methods resolve a force into components—that is, we may find by rules similar to

those given on page 26 the forces in two or more specified directions, which would be equivalent to the given force.

Resultant of Parallel Forces.—Procure two spring-balances reading up to 10 or 15 pounds; also a wooden rod, C D, five feet long and about seven eighths inch square. Drive two nails, E and F, three feet apart and at nearly equal heights, Hang the balances at A and B, from E and F, by cords whose lengths can be readily changed to make up for the stretch of the springs. To determine the resultant of parallel forces in the same and opposite directions, you may perform the following experiments:

Fasten the balances to the points G and H of the rod exactly 3 feet apart and about one foot from each end. Adjust the cords until C D is horizontal, and read the balances. This reading, which will be called the *zero reading*, is to be allowed for in all other readings. Hang a weight K of 6 pounds at L just 1 foot from H, and therefore 2 feet from G. Adjust the cord until C D is again horizontal (to have it at right angles to the forces). Read A and B, and allow for zero readings. The pull on A will be found to be about 2 pounds, that on B about 4 pounds. As the system is at rest, we have an equilibrium of three forces, viz., the downward weight K and

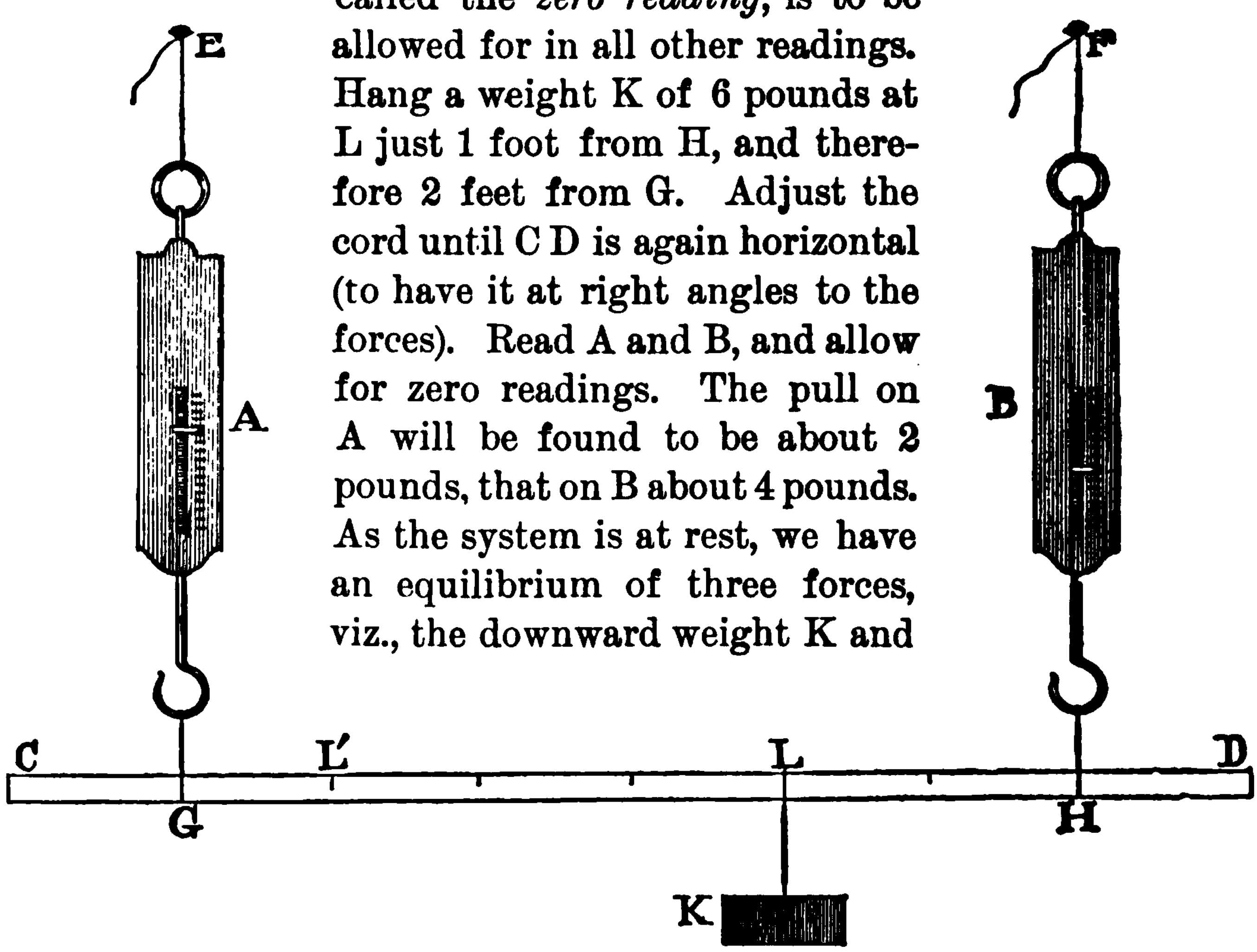


FIG. 27.—TO ILLUSTRATE RESULTANT OF PARALLEL FORCES.

the upward elastic forces exerted by A and B. The weight of the bar does not affect the results, as it is allowed for in zero readings.

Notice three facts: First, the three forces are parallel and in the same plane; second, the sum of the forces (2+4) in one direction (up-

ward) is equal to the force (6) in the opposite direction; and third, the force A is to the force B as the distance L H is to the distance L G—that is, the forces are *inversely* as their respective perpendicular distances from the opposite force.

Try again, using $K = 12$ pounds and making L′ 6 inches from G, so that L′ G : L′ H = 1 : 5. You will now find, on making C D horizontal that A reads 10 pounds and B 2 pounds. $A + B = 10 + 2 = 12$ pounds, the same as K. A : B = 10 : 2 = L′ H : L′ G, and the forces are parallel. A similar result would be found if the downward force were applied anywhere between the two upward forces.

If you put the weight on outside of G or H, the apparatus will overturn and no equilibrium will be produced.

When there is Equilibrium, the resultant of any two of the forces must be equal and opposite to the third. Let us first consider the two upward forces. Their resultant must be equal and opposite to the downward force. Therefore, from the result of the experiment, we may say that—

For two parallel forces in the same direction, the resultant is in the same direction and parallel, is in the same plane as the components, and is equal to their sum. Its line of action is nearer the larger force, and its perpendicular distance from the lines of actions of the two forces is inversely as the magnitudes of those forces.

Consider the upward force A and the downward force K. The resultant of these must be equal and opposite to B. Note that B is equal to the difference of K and A, and is outside of the line of action of the two forces on the side of the greater force K. Hence—

For two parallel forces in opposite directions, the resultant is in the direction of the larger force and is parallel to the components and in the same plane. It is equal to their difference, is outside of the two forces, and on the side of the larger force.

Resolution of Parallel Forces.—By an application of the rules just deduced for the resultant of parallel

forces, we may resolve a given force into parallel components.

To illustrate: Suppose two men, A and B, to be carrying between them, on a board 6 feet long, a rock weighing 100 pounds. The rock is 2 feet from A. How much weight is each man bearing? The load W_1 on A must be to that W_2 on B inversely as their distances from the rock—that is, $W_1 : W_2 = 4 : 2$. Hence, $W_1 : W_1 + W_2 = 4 : 6$. But $W_1 + W_2$ must be 100 pounds, therefore $W_1 : 100 = 4 : 6$ and $W_1 = \frac{400}{6} = 66 \cdot \dot{6}$ pounds. W_2 is then equal to $100 - 66 \cdot 6 = 33 \cdot \dot{3}$ pounds.

QUESTIONS.—How may forces be represented by lines? Represent two forces acting at a point A and at an angle of 45° to each other, one of 5 pounds, the other of 8 pounds. How much would be the resultant of these two forces if acting simultaneously, and what would be its direction?

A large rock is to be moved northward; two horses are attached to it, one of which, A, always pulls 200 pounds, the other, B, 300 pounds. If A pulls south and B north, what will be the resultant pull and in what direction? If A pulls northeast and B northwest, what will be the amount and direction of the resultant pull? In what direction must both pull to give the maximum resultant? How much will that be? Could they pull in any other directions so as to give a resultant in a northerly direction?

Two men are pulling at opposite ends of a rope, fastened in which is a spring-balance; A is pulling with a force of 50 pounds. How hard must B pull to prevent the rope from going toward A? How much will the spring-balance read?

Three men, A, B, and C, are pulling horizontally on ropes knotted at one point as in Fig. 24. A pulls north 20 pounds, B southeast 50 pounds, C southwest 30 pounds. To what single pull would these three simultaneously applied be equivalent? In what direction and by what amount should C pull just to produce equilibrium against the joint pulls of A and B? In what direction and by what amount should a fourth man pull just to neutralize the pulls of A, B, and C in the first case?

A man fastens the cord of Fig. 24 to a stake in the ground at C and another at B, and pulls at D horizontally with a force of 20 pounds, the knot being at such a point that A C is northwest, A B northeast, and A D south. What is the pull in A B and in A C?

Draw a diagram in which the angle B A C will be very large, nearly 180°, so that A is nearly in line with B and C, and find the pull in each for a pull of 1 pound at D. (This would be the condition of things in a stretched line with a weight hung about at its middle.) Stretch a clothes-line between two hooks and hang a weight upon it near the middle. Is the pull along the line and on the hooks greater or less than the weight hung on the line? As the line is more nearly straight with the same weight, is the lengthwise pull greater or less?

Why do the linemen leave a considerable sag in electric light and telegraph wires? Can you stretch a long rope perfectly straight horizontally? Why?

A weight of 50 pounds rests on the top of a wooden frame shaped like a letter Y upside down, whose arms are at right angles with each other. How much pressure is transmitted down each arm?

A man wishes to draw a heavy stone toward a tree by means of a long rope with a much greater force than he can exert by a direct pull. How can he do so?

In the apparatus of Fig. 27, K is 20 pounds and is half-way from G to H. What is the pull upon A and B? If it is one sixth of the way from H to G, what will be the pull upon A and B?

State the rules for the resultant of two parallel forces in the same direction; in opposite directions.

A bridge weighs 100 tons, and its weight is uniformly distributed throughout its length. How much does it press down on each abutment? Neglecting the weight of the bridge, suppose an engine weighing 30 tons is on the middle of a bridge. How much of the load does each abutment carry? Suppose the engine is one third of the way from one end of the bridge, how many tons' pressure due to the engine are there on each abutment? How many tons due to engine and weight of bridge together?

A man and a boy have to carry together a heavy object of whose weight the man can carry just three fourths and the boy one fourth. If they hang it on a stick between them, at what point on the stick must it be fastened?

MOMENT OF FORCE.—CENTRIFUGAL TENDENCY.

Arm of a Force.—Moment.—Sometimes an object is pivoted, so that it can not move bodily onward with respect to what it is attached to, but can only revolve. For instance, a wheel can turn around on its axle, but can not leave the wagon. A force applied to such a pivoted object can merely accelerate its rotation about the pivot.

Procure a wooden rod about 2 feet long, 1 inch wide, and half an inch thick. Bore a smooth hole near one end, A (Fig. 28), and put through it an easily-fitting wire nail or screw. Drive this into a block standing out from a vertical surface. At B, connect a spring balance,* as shown in the figure, fastening its top by a cord to a nail, as at D. Draw up the balance cord until A B is horizontal; slide E along until D E is at right angles to A B, and read the balance. Call this its zero reading. To make an experiment, hang a weight W, of 5 pounds half-way from the pivot O to the

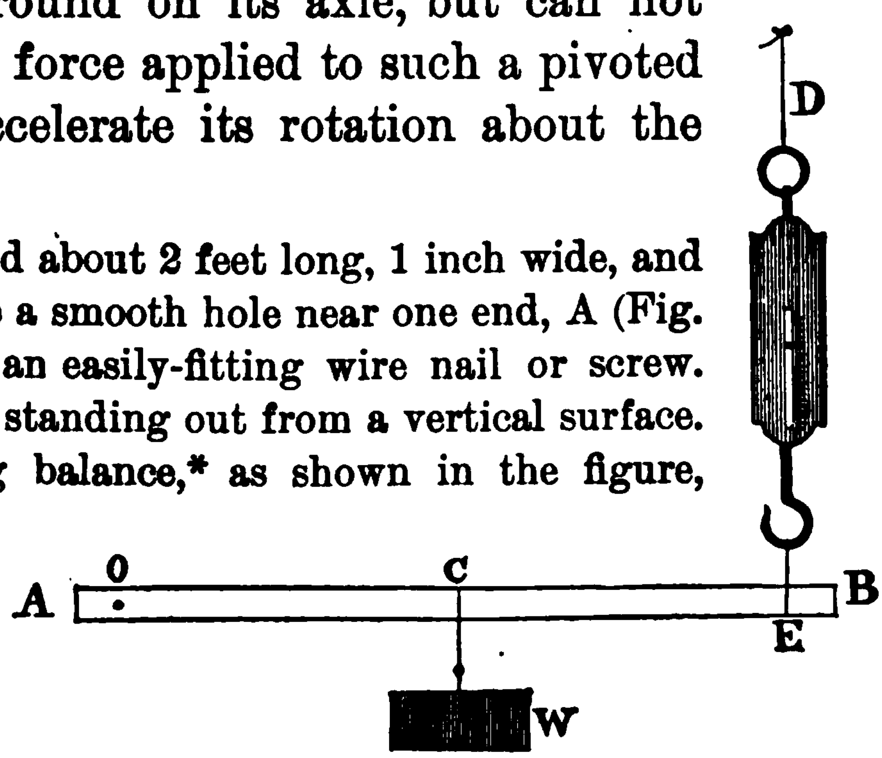


FIG. 28.—TO ILLUSTRATE THE ARM OF A FORCE.

* Instead of the balance, a cord, pulley, and weight, as in Fig. 24, may be used.

point E. Draw up the cord D until A B is horizontal. Read the balance, and allow for the zero reading. The corrected reading will be found to be $2\frac{1}{2}$ pounds—that is, just one half W. Call the force exerted by the balance, F; then we have two forces, F and W, acting at different distances, O C and O E, from the axis, these distances being measured at right angles to the line of action of the forces. We have seen when O C was one half of O E that F was one half of W. Make O C one third of O E, and W 6 pounds. Then you will find, on adjusting and correcting, that F is 2 pounds, or $\frac{1}{3}$W.

Put in another nail, to hang the balance so that E will come about half-way along the rod. Adjust the rod horizontally, and take the zero reading as before. Put on the weight W, or 6 pounds, near the end of the rod, so that W will be on the other side of E from O, and so that O C will be twice O E. Then you will find F to be 12 pounds—i. e., twice W.

You see, then, that in all cases

$$\frac{O\,C}{O\,E}=\frac{F}{W}\;\therefore\;W\times O\,C=F\times O\,E.$$

The distance O C or O E, measured from the axis of rotation perpendicularly to the line of action of the force, is called the Arm of the force, or sometimes the Lever Arm. The product of a force into its arm is called the Moment of the force. Thus, W×O C is the moment of the force W with respect to the axis O, and F×O E is the moment of F. A moment is said to be *right-handed* when it tends to produce rotation in the direction of that of the hands of a clock, and *left-handed* when the tendency is in the opposite direction. Thus, in the experiment, the moment of W was always right-handed and that of F left-handed.

Equilibrium of Moments.—We see, then, that in each case in our experiment there was equilibrium when the right-handed moment (W×O C) was equal to the left-handed moment (F×O E).

A body may be acted upon by any number of forces. Take the case where these act in any direction whatever in the same plane or in parallel planes. They will be in equilibrium when the sum of the right-handed moments is equal

to that of the left-handed moments. This may be proved by means of the apparatus numbered 5 in the illustration on page 60.

Couples.—If two equal and opposite parallel forces act upon a body, they are called a Couple. We have shown that the resultant of two parallel forces is equal to their difference; when the forces are equal, their resultant, therefore, is zero. A couple does not tend to move a body as a whole.

Let F_1 and F_2, applied at the points a and b, represent a couple. Draw a line $c\ d$ perpendicular to and joining the lines of action of the two forces. Then $c\ d$ is called the arm of the couple. The moment of the couple is the product of either force into the arm $c\ d$—i. e., moment $= F_1 \times c\ d = F_2 \times c\ d$.

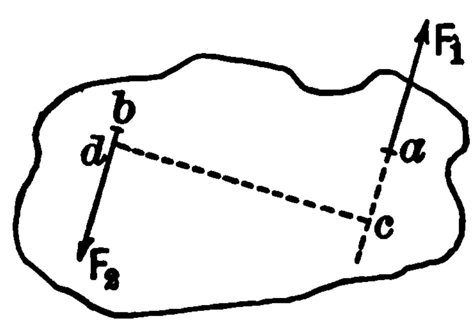


FIG. 29.—A COUPLE.

A couple can not be counterbalanced by any single force, but requires the application of another couple opposite in direction and of equal moment in the same or a parallel plane.

Central Force; Body revolving in Circle.—Tie a small stone, or any dense object, at the end of a strong cord two or three feet long. Swing the stone around the hand so that it revolves, at a nearly uniform speed, in a circle, as A E F G, Fig. 30. You will notice that you are obliged to exert a steady pull or force upon the cord in order to keep the stone from flying away from you. The cord serves merely to transmit this force from your hand to the stone, thus pulling the stone continually toward the hand.

A body revolving uniformly in a circle must be acted on by a constant force toward the center of the circle.

While the stone is revolving, let go or cut the cord at any instant. The stone will fly off in some direction. What will that direction be? Try the experiment several times by swinging the stone in a horizontal circle, just above a smooth floor, and looking down upon it from above. The curved path due to gravity will thus be avoided. Note carefully the direction in which the stone flies off each time. You will see that

this is the direction of the straight line tangent to the circle at the point at which the stone was at the moment of release. For instance, if it were at A, Fig. 30, when you let go the cord, it would move off along the straight line A B D, tangent at A. The tangent is the direction of motion of the stone (page 16) at that instant. It is evident that this must be the case, because, after you release the cord, the stone moves off merely by virtue of its inertia, and must, therefore, follow the law of inertia as expressed by Newton's first law of motion (page 31). If, then, the body A is revolving uniformly in the circle A E F G with such a velocity that it would pass from A to E along the circle in a given time, it would, if released at A, pass along the straight line A D with the same velocity, reaching a point B such that A B = A E in that time.

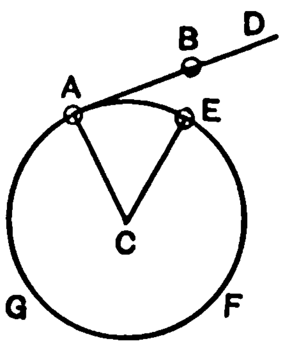


FIG. 30.

An object thus revolving, therefore, tends to fly off at a tangent, and with the same velocity that it is moving along its path. Every point beyond A of the tangent A B D is farther from the center than the circle itself. Hence we may say that the object tends to fly away from the center; but notice that it does not tend to fly off radially. This tendency may be called the Centrifugal (*flying from the center*) Tendency. The force required to keep the body in its circular path is called the Centripetal (*center-seeking*) or Central Force.

Give the cord a certain length, perhaps six inches. Whirl the stone twice a second. Notice the pull (central force) which you give. Then whirl the stone twice as fast—that is, four times a second. Notice that the central force required is much greater. In fact, with double the number of turns, the force required is four times as great; with treble the number, nine times, etc. *The central force is, therefore, proportional to the square of the number of turns per unit of time*, the radius remaining the same.

Now make the radius twice as great and turn, as at first, twice a second. The central force required will be twice as great. If the radius be made three times as great, the

force will be three times that exerted at first. *The central force is, therefore, directly proportional to the radius of the circle,* the number of turns remaining the same.

Compare the pull required for two stones, one of twice the mass of the other, but whirled in circles of equal radii and at the same rate. *The central force will be found proportional to the mass.*

The velocity of the body in the orbit being uniform, the central force is doing no work. Its effect is merely continually to change the direction of motion of the body. The centrifugal tendency of the body is erroneously called "centrifugal force." It is not, however, a force at all. The only force exerted is the centripetal or central force, which is of such an amount as to change the direction of the momentum just fast enough to keep the body moving in the circle.

When you are whirling a stone in a vertical circle, you will notice that the pull is greater when the stone is at the bottom of its path and less when it is at the top. This is because at the bottom you have to exert the central force plus the weight of the stone, and at the top only the central force minus the weight. If the stone is revolving at such a rate that the central force is less than the weight, then it will not rise to the top of the circle, but will go up part way and fall, as you can see by making the stone whirl fast and then allowing it to slow down by the resistance of the air.

Every Revolving Object affords an Example of Central Force and centrifugal tendency. The grandest illustration to be found is in the motions of astronomical bodies. The moon revolves around the earth in a nearly circular orbit, and is held in that orbit by a central force, which we are next to study under Gravitation. Similarly, the earth and all the planets revolve in orbits about the sun, the central force again being gravitation. If gravitation were to cease, all the heavenly bodies would move off in straight lines, and the entire order of the universe would be changed.

As the earth, a wheel, or any object, revolves upon its axis, every particle of matter in it tends to fly off at a tangent. To prevent this motion, some force—cohesion, gravitation, etc.—must be exerted. You know how mud flies from

a rapidly turning carriage-wheel. This is because the force of adhesion of the drops to the wheel is not great enough to overcome the centrifugal tendency, or, in other words, to change the direction of the momentum of the drops fast enough to keep them against the surface of the wheel.

Objects resting upon the surface of the earth are held in place by their weight, although, owing to the revolution of the earth upon its axis, they have a centrifugal tendency. But if the earth were to revolve about seventeen times as fast as it now does, objects at the equator would have a centrifugal tendency equal to their weight, and would fly off at a tangent.

A grindstone, revolving rapidly, throws off water from its wet surface for a similar reason. If the stone be revolving very fast, the centrifugal tendency of its outer portion may become greater than its cohesion can withstand, so that it will fly asunder, its parts moving off with great energy. Large stones bursting in this way may do much damage; and heavy fly-wheels of engines, or other parts of machinery which revolve at high speed, must be carefully designed, so that they may be strong enough to resist the centrifugal tendency.

EXPERIMENTS.—Suspend a tumbler by a stout cord tied about it so that it will hang upright. Partly fill it with water. Twist the cord around several times and then let it untwist, twirling the tumbler. Notice how the water moves outward, piling up at the side of the tumbler, and even flying out over the edges if the twirling is fast enough. What does this illustrate?

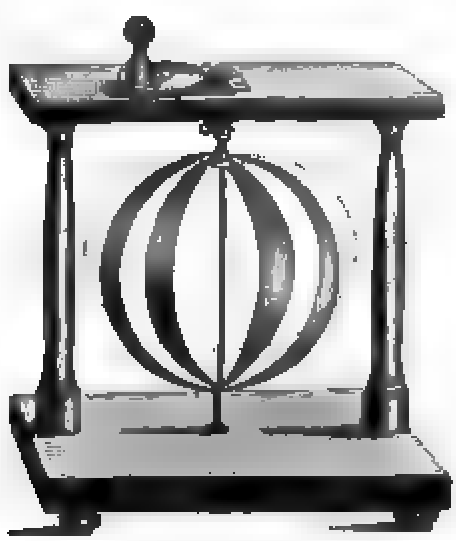


FIG. 31.—WHIRLING-MACHINE.

Whirl the apparatus shown in Fig. 31. Notice how the hoops bulge at the equator, being drawn in at the poles. How is this owing to centrifugal tendency? Why is the action more pronounced at higher speed? What prevents the hoops from flattening out entirely? Suppose the earth were slightly fluid or pasty, and were revolving on its axis as it now does, what form would it take? Why? The earth

actually has such a form, and doubtless from the action of this cause when it was in a less rigid condition than now. Why is the centrifugal tendency greater at the earth's equator than at the poles?

This fact enables us to account for the difference of weight of a given body at various parts of the earth's surface. At the equator, the body has the greatest centrifugal tendency, and is also farthest from the earth's center; its weight from both of these causes is less than elsewhere on the earth. At the poles it would be nearest to the center and would have the least (in fact no) centrifugal tendency. Its weight would, therefore, here be the greatest. At intermediate latitudes, the weight would be between these two extremes.

When a railroad train is going round a curve, the centrifugal tendency must in some way be neutralized. To do this, the outer rail is raised higher than the inner one. The weight of the cars (acting through their center of mass) may then be resolved into two components, one perpendicular to the inclined bed of the track and simply pressing the train against the track, the other horizontal and toward the inside of the curve. The latter will then give the necessary central force. The tangential component will differ in amount with the speed of the car, so the track can not be laid to suit all speeds; it is designed only for the greatest speeds. You will, therefore, not feel the tipping on the curve in a fast-running train, while you will notice it on the same curve in a slow train. Why does a bicycle-rider, in going rapidly round a curve, lean toward the inside of the curve?

Questions.—If, in the apparatus of Fig. 28, W is made 10 pounds, and is one fifth of the way from O to E, what will the balance read? Reverse the positions of balance and W, and what will the former read?

What is meant by the moment of a force? By the arm of a force?

A force of 6 pounds acts on a pivoted body at such a point that the perpendicular distance from the pivot to the line of action of the force is 8 feet; what is the moment of the force? What is meant by right-handed and left-handed moment? Suppose the moment in the preceding problem were right-handed, how much would be the magnitude of the moment required to counterbalance it? What must be its direction? If its arm were 9 feet, what must be the amount of the force? Draw various diagrams representing a pair of forces whose moments are counterbalanced.

A boy weighing 50 pounds sits on one end of a board placed across a log, and another boy weighing 100 pounds sits on the other part of the board; how far out from the log must the second boy sit to balance the first? How much will be the downward pressure upon the log?

The forces of a couple are 20 pounds each, and their perpendicular distance apart is 4 feet, what is the moment of the couple? Define a couple.

What kind of a force is necessary to keep an object revolving uniformly in a circle? In what direction does such an object tend to fly off if that force ceases? Why? Why may this tendency be called a centrifugal tendency? Why is it

better called a tangential tendency? Why should it not be called a centrifugal force? What is meant by central force? By centripetal force? What does this force do? Does it perform any work on an object revolving in a circular orbit? Why?

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Why does the weight of a body differ at different points of the earth's surface? If a standard pound-weight and a weighed pound of shot were exactly balanced at Chicago, would they cease to balance each other if transferred to Quito? If you should buy a quantity of nails in the city of Mexico that would weigh exactly a pound on a spring-balance, would they weigh more or less than a pound on the same balance at Hammerfest in Norway? Why?

Construct a diagram showing what must be the direction followed by a barge drawn by two horses on opposite sides of a canal.

Illustrate in a similar manner the resultant in the case of the onward motion of a swimmer striking the water with both hands; the darting of a trout in a straight line by the action of two pectoral fins.

Of what tendency is advantage taken in discharging a stone from a sling? Have you read of instances in history where sufficient velocity was in this way communicated to projectiles to render the sling a formidable weapon?

Why are cushions and hair mattresses soft and comfortable? On what does the action of carriage-springs depend?

There is a legend that in an exhibition of skill Richard the Lion-hearted severed an iron bar with his sword, while Saladin surprised his opponent by cutting a feather pillow in halves with his scimiter. Explain the principles which made these feats possible.

Have you ever seen the animals in a cattle-train thrown violently off their feet when the cars are suddenly stopped? Why is this?

In accordance with what principle do athletes make longer running- than standing-jumps?

On the top of one of the fingers of your left hand, balance a card with a penny placed upon it; strike the card suddenly with the middle finger of the right hand, when it will fly away and the penny remain on the finger. Why?

Suppose that a leader of silk-worm gut will just pull out a spring-balance to the 6-pound notch without breaking. How much strain will it bear from the angler and from the salmon when they are pulling at cross-purposes?

Why does a gunner follow flying game with his piece before firing?

Each of the chain of bones forming your spine is separated from its neighbors by disks of elastic tissue. What happens, then, when you jump heavily on your feet from a height? Is the brain seriously jarred? Can you think of a reason why a man is a little taller in the morning than at night? Why you should not form the habit of sleeping on a high pillow?

Enumerate all the forces acting upon a ball thrown into the air. As its velocity diminishes, what is its direction? Why is it found necessary to elevate a rifle in order that the bullet may strike a distant target?

May gravity be nullified by the centrifugal tendency?

If a stick 10 feet long is supported at a point 3 feet from one end, what weight hung from this end will be supported by 12 pounds hung from the other?

Have you ever seen two buckets evenly balanced in a well at opposite ends of a rope? Explain this as a simple example of equilibrium of forces.

Suppose a vessel steaming at the rate of 12 miles an hour to be ascending a river the velocity of whose current is 2¼ miles an hour ; at what rate will it progress ? What will be its speed in descending the same river ?

A locomotive weighing 20 tons moves with a velocity of 40 feet a second. Another locomotive weighing 25 tons moves at the rate of 4,800 feet in a minute. How do their velocities compare ? How do they compare in momentum ?

If the wind is blowing southwest with a velocity of 10 miles an hour, what are the southerly and westerly components ? *Ans.* 7·07 each.

Assume that two hunters are carrying a deer suspended from a pole resting on their shoulders. What is the proportion which each bears—

1. When the deer is half-way between them ?
2. When its distance from the first is four times its distance from the second ?

GRAVITATION AND THE PENDULUM.

UNIVERSAL GRAVITATION.

Every Particle of Matter tends to approach every other Particle; or, in other words, any two particles of matter whatever will be accelerated toward each other unless such motion is prevented. There appears, therefore, to be some form of energy which causes a universal force of attraction. This force is called Universal Gravitation. The nature of the energy causing it is unknown. The law which expresses the action of the force of gravitation was first stated by Newton, and is as follows :

1. Every particle of matter in the universe attracts every other particle.

2. The direction of the force between any two particles is that of the straight line joining them.

3. The magnitude of the force is directly proportional to the product of the masses of the two particles, and inversely proportional to the square of their distance apart.

A Homogeneous Spherical Body, with reference to any body outside itself, acts as if all its mass were concentrated at its center. Thus, two spheres of uniform material attract each other with a force proportional to the product

of their masses divided by the squares of the distance between their centers.

Gravitation appears to act Instantaneously.—There is reason to suppose that if a new mass of matter could be created suddenly in space, its attraction would be felt in an imperceptibly short time on every existing particle of matter, at least within the limits of the visible universe.

Gravitation between two Bodies is not affected by interposing any other Body.—When the moon, for instance, passes into the shadow of the earth and is eclipsed, the earth is directly between the moon and the sun; but the attraction between the moon and sun is apparently not in the least diminished or increased in consequence. A body weighed in the air shows no apparent change in weight by placing other objects between it and the earth, the very minute increase due to the attraction between such objects and the body being imperceptible.

The energy which produces universal gravitation is the source of the immense forces necessary to keep the planets in their orbits around the sun, and, indeed, to hold together the whole astronomical system. Some idea of the amount of the force of attraction due to gravitation may be obtained from the statement that two homogeneous spheres, each having the mass of one ton and at a distance of 10 feet between centers, would attract each other with a force of only a little more than a millionth of the weight of a pound; whereas, the force of attraction between the moon and the earth is equal to the weight (at the earth's surface) of twenty quadrillion tons. The weight of the moon's mass at the earth's surface would be about 3,600 times as great as this. The forces exerted among astronomical bodies are inconceivably immense only because the masses of these bodies are so vast; but, owing to the great distances between the bodies, the forces are small as compared with the weight of equal masses at the earth's surface.

It was from the mathematical laws governing the motions of the planets, the forms and sizes of their orbits, and their times of revolution in these orbits, that Newton deduced the Law of Gravitation.

Weight is, as has been stated, merely a familiar example of universal gravitation. As the earth is nearly a sphere,

weight acts toward its center. A cord, by which any body is suspended—e. g., a plumb-line—will then be always vertical—that is, will point toward the center of the earth.

This statement, however, is not strictly true. A plumb-line at the foot of a mountain will not hang precisely vertical; but its lower end will incline a little toward the mountain because the mass of the bob will be sensibly attracted sidewise by that of the mountain. The amount of this inclination is very slight, but has been indirectly measured.

Weight above and below the Earth's Surface.—Bodies become lighter as they are taken up from the earth's surface; but since the force diminishes as the square of the distance from the center (not from the surface) of the earth, and as the center is 4,000 miles below the surface, the diminution is small.

A body weighing 1,000 pounds at the earth's surface would weigh (on a spring-balance graduated at the surface) only one pound less at a height of two miles. At the distance of the moon from the earth (240,000 miles), the same body would weigh less than five ounces.

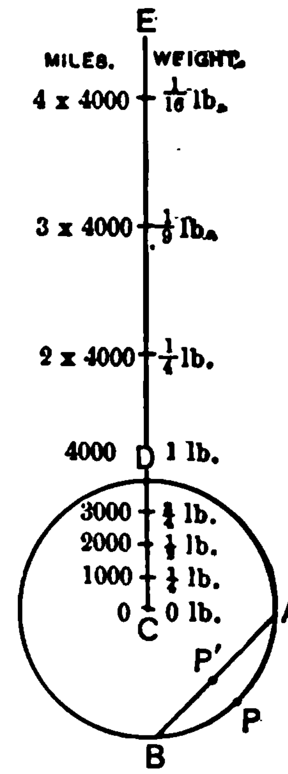


FIG. 32.—DIMINUTION IN WEIGHT ABOVE AND BELOW THE EARTH'S SURFACE.

A body below the surface of the earth weighs less than at the surface because some of the mass of the earth is now attracting upward. At the center of the earth the body would have no weight.

For example, a body at P′ (Fig. 32) would have above it all that portion of the earth included between the plane A P′ B and the surface A P B. This portion would be attracting it upward—i. e., toward the surface—while the rest would be pulling it downward—i. e., toward the center. The resulting downward pull would be the difference between these two. At the center, the portions on opposite sides of any plane would be equal.

Falling Bodies.—All free bodies, whatever their mass, fall toward the earth with equal accelerations. If one body possesses twice the mass of another, twice the force will

be required to give it the same acceleration; but the weight is proportional to the mass, and the weight is the force causing the fall. Hence the body of twice the mass has twice the force (weight) acting upon it, and therefore moves with the same acceleration. The size, shape, and material, make no difference, for the acceleration of a free body is determined only by its mass and the acting force.

Fig. 33.

But bodies falling through air are not entirely free, for the air offers a resistance tending to retard their motion. This resistance is due partly to friction, partly to the work necessary to displace the air in front of the moving body. Its amount is greater the faster the body moves, the larger the body is in proportion to the mass, and the more irregular its shape.

Thus some objects, such as the seeds of dandelions and thistles, or feathers, wool, fine dust, a spread umbrella point upward, fall very slowly through air, while bodies of equal mass in compact form would fall much faster.

This may be illustrated by an experiment with the "guinea and feather tube" (Fig. 33), a long glass tube containing a coin and a feather or bit of paper. Invert the tube, and you will see the metal drop quickly to the bottom while the feather falls slowly, just as they would act in the air outside. Connect the tube with the air-pump and exhaust part of the air. The metal will still fall faster on inverting the tube, but the feather less slowly than before. Pump out all the air possible. The feather will now fall nearly or quite as fast as the metal. If you could remove all the air, they would fall equally fast, and both would fall slightly faster than the metal did through the air.

Free Falling Bodies move with Uniformly Accelerated Motion.—This fact has been established by careful measurements, and yet the statement is not strictly true. Uniform acceleration can be produced only by a constant force, and the weight of bodies increases slightly as

they approach the earth. Weight is sensibly constant, however, within vertical distances of a few thousand feet.

Falling bodies, therefore, afford a special example of uniformly accelerated motion, and must follow the laws given on page 20. The rate of acceleration at places not far from latitude 45° and not more than a mile above sea-level, is about 980 centimetres or 32·2 (roughly 32) feet per second. This is the quantity a in the formulæ, and is often denoted by g. Owing to the resistance of the air, results calculated by these laws for bodies falling in air will be inexact. If a stone falls in air, it will meet with a continually increasing resistance. After it has fallen a few hundred feet, this resistance will become equal to its weight, so that the body will cease to be accelerated and will fall at a uniform speed.

Projectiles.—A bullet discharged from a gun, an arrow from a bow, a stone thrown by the hand, are examples of Projectiles. The figures on pages 55 and 56 show the paths which projectiles would take on being discharged at various angles to the horizontal, provided no resistance were offered by the atmosphere. The path A B′ C′ would be in any case a portion of a curve called a *parab′ola.*

It may be shown mathematically that the horizontal distance A I′, which a projectile would traverse before coming to the ground, if started with a given velocity, will be greatest when the initial direction A B is at an angle of 45° to the horizontal. If fired at a greater or less angle, the projectile would reach the ground sooner. The actual *best angle* is somewhat less, owing to the resistance of the air. In whatever direction the projectile is thrown, the air continuously retards its motion. Thus, if it were not for air resistance, a body thrown upward would have the same velocity on reaching the earth as at starting; but the air continuously slows its speed, so that it rises less high and strikes the ground with less velocity than it otherwise would.

Questions.—What is Universal Gravitation? To what form of energy is it due? State the law of gravitation. In reckoning the attraction of a sphere, at what point may we consider its mass as concentrated? How much time does it require for gravitation to act between sun and earth? Is gravitation affected by interposing objects between the attracting particles?

What is meant by the term Weight? In what direction does weight act? At what rate does weight diminish as we ascend from the earth's surface? A man who learned that weight diminishes as the square of the distance, proposed that soldiers should carry their knapsacks supported on the muzzles of their muskets, as the knapsacks would then be about twice as far from the ground and would therefore weigh but one fourth as much. Where was his fallacy? Why does weight diminish as we descend into the earth? What do we mean by "up" with reference to gravity?

At the bottom of a mine 1,000 feet deep, how much would the mass of a pound weigh? How much at a height of 1,000 feet above the surface? Does weight diminish more rapidly in descending into the earth or in rising above it? What would be the weight of a body at the center of the earth? What would be its mass? Does weight have anything to do with producing the mass of a body? Does mass have anything to do with producing the weight of a body?

With what kind of motion do free bodies fall toward the earth? What kind of force is necessary to produce uniformly accelerated motion? Is it then strictly true that the motion of freely-falling bodies is uniformly accelerated? Why does it appear true in our ordinary experiments? If a body were to fall toward the earth (in a vacuum), would its rate of acceleration slightly increase or slightly diminish? Why? If a body were falling down the shaft of a mine (in a vacuum), what would be the change in its rate of acceleration?

What is the effect of air upon the motion of falling bodies? What is meant by a projectile? Why do projectiles near the earth's surface not travel in straight lines? If a projectile were moving in free space at such a distance from all bodies that gravitation was insensible, in what path would it move? Why?

In the following problems, the resistance of the air is to be disregarded unless otherwise stated: In a freely-falling body what would be the velocity after 3 seconds? How long would it take a body to acquire a velocity of 3,220 feet a second? How far will a body fall in one second? In two seconds? In three? In four? How far does it fall during the first second? During the next? During the third? The fourth? How long will it take a body to fall 100 feet? A stone is dropped or thrown horizontally from the top of a cliff and reaches the bottom in 3·5 seconds. How high is the cliff? A stone is thrown vertically upward with a velocity of 50 feet a second. How high will it rise? How long will it remain in the air?

Does the resistance of the air arrest or oppose gravity in the case of projectiles? Can you think of a reason why wind-gauges are used on rifles? If a ·44-inch caliber bullet were discharged vertically upward from a Winchester rifle, would it gather sufficient energy in its descent to strike with fatal effect? Would a charge of swan-shot? Why? Can you conceive how the laws relating to projectiles are taken advantage of in military science?

CENTER OF MASS.

Center of Weight or Mass.—Let A and B be two homogeneous spherical particles of any size and mass. Suppose them to be connected by a rigid rod, which for convenience we will assume to have no mass. Let the lines

W_1 and W_2 represent their weights. These will be proportional to their masses, and will act as if the mass of each were concentrated at its center. Then W_1 and W_2 form a pair of parallel forces in the same direction. Their resultant will be parallel to them and equal to their sum—i. e., $R = W_1 + W_2$. The distance of the resultant from each will be such that $W_1 \times ac = W_2 \times bc$—that is, so that $ac : bc = W_2 : W_1$. For example, if $W_1 = 1$, and $W_2 = 3$, then $ac : bc = 3 : 1$, or ac must be three times bc.

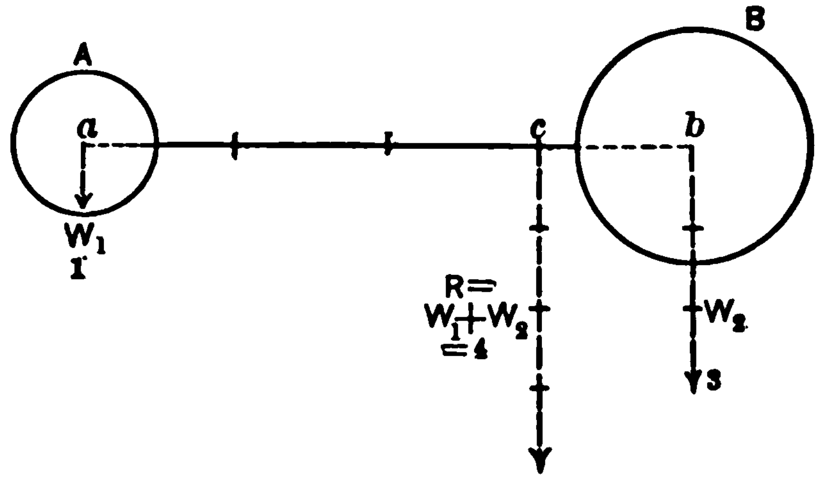


FIG. 34.—RESULTANT OF WEIGHT OF SYSTEM PASSES THROUGH CENTER OF MASS.

If ab is not horizontal, then let Fig. 35 represent any other position. Now, R must always be parallel to W_1 and W_2, and at such a distance that $W_1 \times ac = W_2 \times bc$—that is, that $ac : bc = W_2 : W_1$. For $W_2 : W_1 = af : ef$, and $ac : bc = af : ef$. Hence $ac : bc = W_2 : W_1$. This is true for any angle or position whatever of the rod. Hence the resultant always passes through one common point, c, whatever the position of the system. If, therefore, a force equal and opposite to R were applied at c, it would counterbalance the weight of A and B and hold up the system just as if all the mass, and therefore all the weight, were concentrated at c. The point c is called the Center of Mass, being the middle point of the mass of the body. It is also known

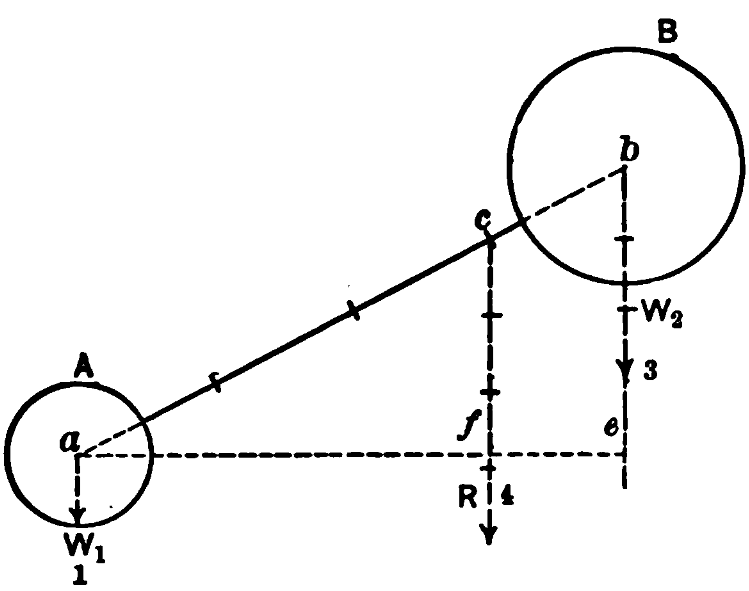


FIG. 35.—RESULTANT PASSES THROUGH CENTER OF MASS IN ANY POSITION OF SYSTEM.

as the Center of Weight, or (as weight is merely a special case of gravitation) the Center of Gravity of the system.

If instead of two particles there were three, we should proceed in a similar manner to find the resultant of the three weights in one position of the system, then in another, and so on; and the intersection of all these resultants would be the center of mass of the system. Bodies are merely collections of particles. Hence

The Center of Mass (of Gravity, or of Weight) of a body is the common point through which the resultant of the weight of all its parts passes, whatever the position of the body.

On consideration, you will see that the center of mass of a body is in general not at what we should call the middle of the body—that is, at the center of its volume—unless the body is homogeneous. A circle of wood, if homogeneous, would have its center of mass at its geometrical center; but if a plug of lead were put into it at *a* (see Fig. 36), the center of mass would be at some position *c*′, between *c* and *a*.

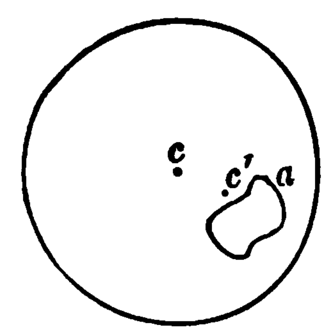


FIG. 36.

EQUILIBRIUM OF BODIES IN RESPECT TO WEIGHT.

A Body is said to be in Equilibrium with respect to its weight when, on being left to itself, motion does not ensue. Let A (Fig. 37) be any body supported on a pivot or axis at *a*, about which it is free to turn. The body will always come to rest with its center of gravity *c* vertically under *a*, as shown in the figure: for, suppose it pulled to one side, so that *c* is at *c*′; then the weight W will have a moment $W \times a'b'$, tending to turn A around *a*′ as a pivot. The only position in which the moment is zero is where *a*′ *b*′ is zero—i. e., when *c* is vertically above or below *a*.

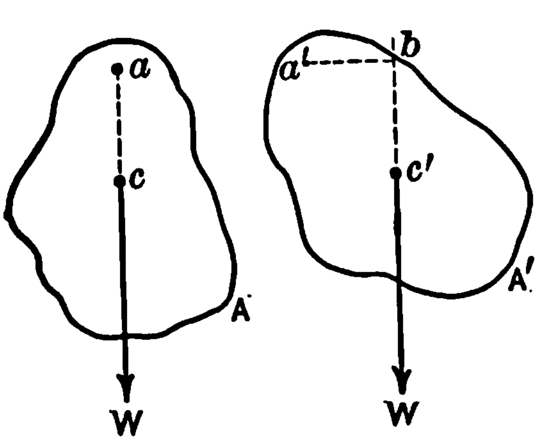


FIG. 37.—EQUILIBRIUM WHEN CENTER OF MASS IS VERTICALLY ABOVE OR BELOW POINT OF SUPPORT.

The body then can remain at rest when left to itself—that is, *can be in equilibrium (in respect to weight) only when the center of mass is vertically above or below the point of support.* This is true of all pivoted bodies.

Plumb-line.—Suppose the body A is suspended from a point *a* by a flexible cord *d a*. When the body is at rest, its center of mass, *c*, and the points *a* and *d*, will all be in the same vertical line, and the cord *d a* will therefore be vertical; for, if either *a* or *c* is out of the vertical, there will be a moment due to the weight and tending to bring them back into the vertical, as in Fig. 37.

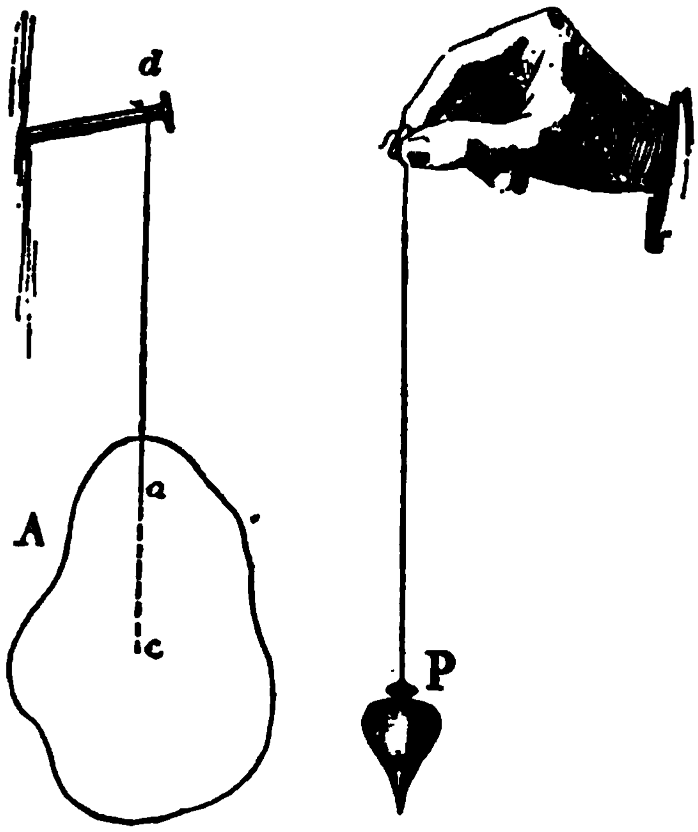


FIG. 38.—PLUMMET FOR OBTAINING VERTICAL LINES.

If the suspended body P (Fig. 38) be homogeneous and carefully turned to a point, and the cord be put in at the proper place, the point of P will also be vertically below the supporting point. Such an arrangement is used by surveyors and others for obtaining vertical lines, and is called a plummet or plumb-line, because the body P is sometimes made of lead (Latin, *plumbum*) on account of the great density of that metal. The line itself is necessarily vertical, whatever the bob be made of, and whatever its shape.

Why does the knife suspended at A (Fig. 39) hang in the position represented when in equilibrium?

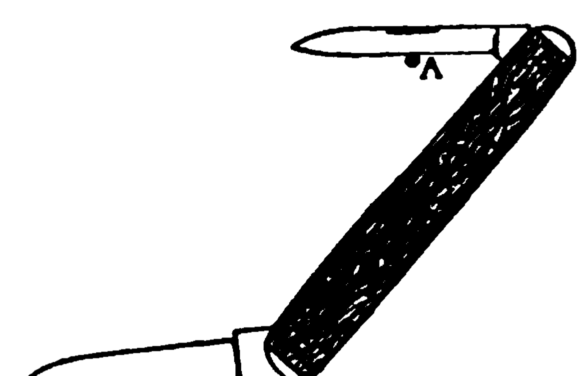


FIG. 39.—SUSPENDED KNIFE.

To find the Center of Mass.—The principle that the center of mass of a free body, when in equilibrium, is vertically under or over the point of support, is made use of to

find experimentally the position of this center. Let the body be hung successively from several different parts. Notice the direction of the suspending cords relatively to the body. These directions will all intersect at one point, which will be the desired center of mass.

By way of experiment, take a piece of cardboard of any shape, say A B C D. Hang it by a cord *h a* through *a* and note the direction *h a d* of the cord (prolonged). Or, better, put a long pin through a hole at *a*. Hang over the pin a little plumb-line, made of a thread and a bit of any heavy substance. Mark with a pencil two points on the cardboard just behind the plumb-line, and draw a straight line through them. Do the same for one or more other holes, *b*, *e*, etc. These lines (dotted) will intersect at or near the same point, *c*, which is the desired center of mass—for the center of mass must lie in each line, and therefore at the intersection. Balance a fork, cane, or chair, on the finger or hand. The center of mass will be at the intersection of verticals through the hand for different positions of the object.

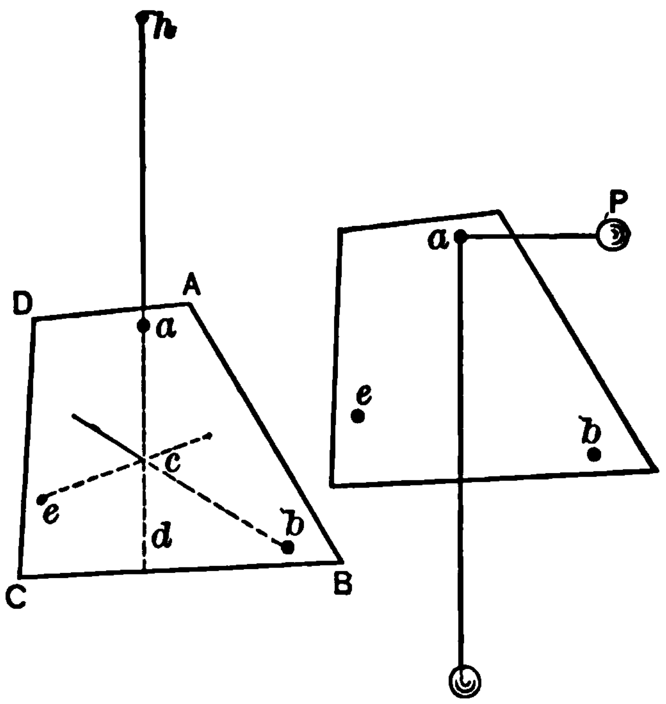


FIG. 40.—ILLUSTRATING METHOD OF FINDING CENTER OF MASS.

Stable and Unstable Equilibrium.—If, in Figs. 37 to 40, *c* be vertically below *a*, then, on pulling *c* to one side, the weight will tend to drag the body back to its position of rest. This condition is called one of *stable equilibrium.* In general, equilibrium is said to be stable when, on being moved, the body tends to return to its original position.

If *c* be vertically above *a*, then, on the slightest motion, the weight tends to tip the body still farther. This condition is called one of *unstable equilibrium.* In general, equilibrium is unstable when, on being moved, the body tends to depart still farther from its original position. In the case of a suspended body it is difficult, if not impossible (unless

there is considerable friction), to adjust the body in the position of unstable equilibrium.

Neutral or Indifferent Equilibrium.—If the point of suspension *a* coincides with the center of mass *c*, then the body will remain in any position in which it is placed, because the weight always acts directly through the supporting point, and its moment must always be zero. This condition is called *neutral* or *indifferent equilibrium.* It is the condition in which the body, on being moved, tends neither to return to, nor to move farther from, its original position.

Equilibrium of Bodies resting on a Surface.—If any body, A, is resting on a surface at only one point, *a*, and *c* be its center of mass, as in Fig. 41, then it is evident that A is not in equilibrium, and can only be so when *c* is directly over *a*. Its equilibrium will then also be unstable. If the body is a spherical one, or a circular one standing on edge on a horizontal surface (Fig. 42), *c* will necessarily be always vertically over *a*, and the body will be always in neutral equilibrium. A sphere or vertical circle on an inclined surface can never be in equilibrium, because *c* can not be over *a*. Any body whatever (Fig. 42) on an inclined surface will be in equilibrium whenever its center of gravity *c* is over its point of support *a*, and only then. The fact that the surface is inclined, so that perhaps the body may slide down, has nothing to do with the equilibrium of the body itself.

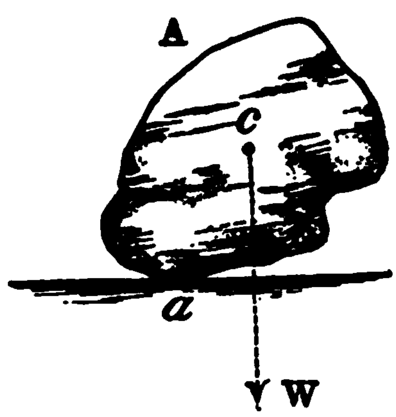


FIG. 41.—STONE TOUCHING AT ONE POINT.

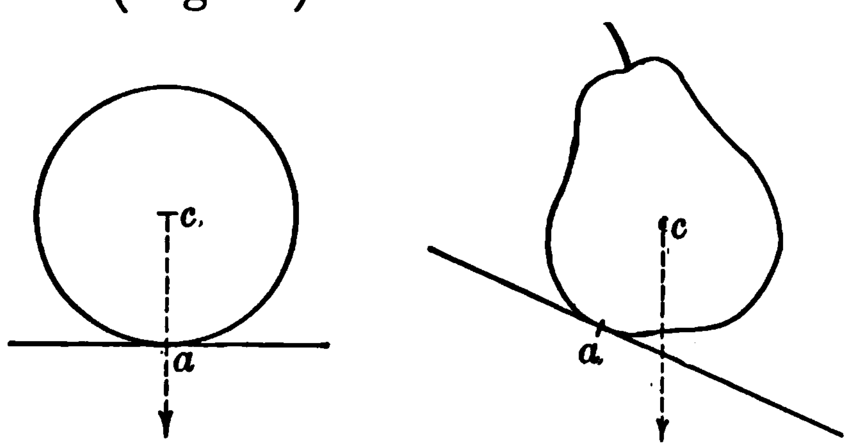


FIG. 42.—EQUILIBRIUM IN CASE OF BODIES RESTING ON SURFACE.

The Base.—Bodies standing by themselves are ordinarily supported by three or more points. A three-legged stool rests upon the floor at the points *a*, *b*, and *e*. Draw lines *a b*, *b e*, *e a*. The surface *a b e* inclosed by these lines is called the Base. If the body rests at several points, the base is the surface inclosed by the lines circumscribing those points. For instance, if a body rests on the points *a b c d*

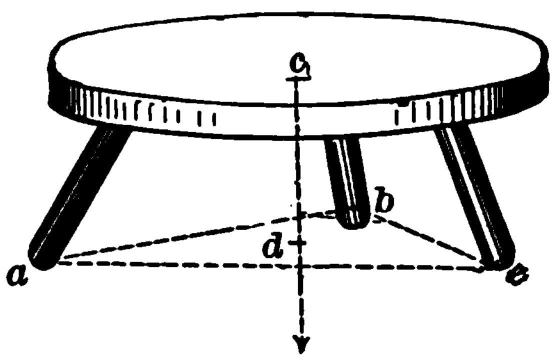


FIG. 43.—ILLUSTRATING THE BASE.

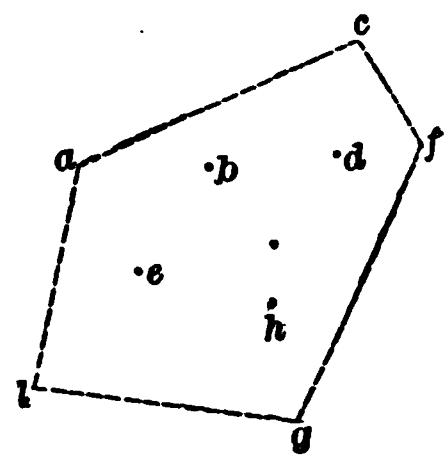


FIG. 44.

e f g h l (Fig. 44), the base would be the surface inclosed by *a c f g l*.

A body is in stable equilibrium only when *the vertical through the center of mass passes through the base.* As soon as the vertical falls outside the base, the equilibrium ceases and the body overturns.

The Degree of Stability depends on the work necessary to overturn the body—that is, to destroy its stability. Let A and B, Fig. 45, represent the same body lying on its side and standing on end. Its degree of stability is greater in the former than in the latter position. Why? Because to overturn it, more work must be done.

What is the work to be done? Take the first position A. To destroy the equilibrium, we must bring *c* up to such a point *c'* that the vertical *c' d* falls just beyond *b*. This requires that the whole mass of the body be raised. We must do work, therefore, against the weight of the body, and, as the weight may be considered as acting through the center of mass, the amount of work done will be the product of the weight into the vertical distance *d c'*, through which the body has been raised. In the position represented in B, the weight is the same, but

the height $d' c'$ is much less. The work to be done is proportionately less. Hence the stability is much greater on the broader base.

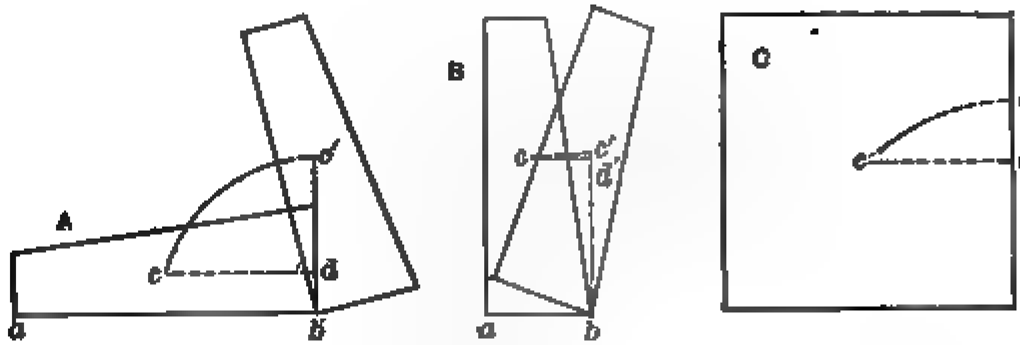


FIG. 45.—ILLUSTRATING DEGREES OF STABILITY.

If the body C is of the same weight as A, and has the same size and shape of base, but is of such a shape or density that its center of mass is much higher, then it will be less stable—for the height $d'' c'$ will be less, and the work done correspondingly less.

Of two bodies with the same base and center of mass at the same height, but of different weights, the heavier will be the more stable, because the work required to overturn it, being the product of the weight into $d c'$, will be greater. To determine, then, which of several bodies or of several different positions of the same body is the most stable, we must ascertain which requires the greatest work to be done in order to destroy the equilibrium by overturning the body.

If it is desired to have any Object or Structure stable, it is necessary to see that the center of gravity shall be over the base. To secure the greatest degree of stability possible, care must be taken to arrange matters so that the amount of work required to overturn the object shall be as great as possible. This is usually accomplished by making the base large and the center of mass low.

QUESTIONS.—Define center of mass; center of weight; center of gravity. Why are the center of mass and the center of weight at the same point? Suppose two particles, of mass 5 and 1 respectively, to be connected by a rigid rod of length 10 and without weight—show where their center of mass is located. Are the center of mass and the geometrical center of bodies generally the same? Why? When is a body said to be in equilibrium with respect to its weight? If a body is suspended so that it can turn about a point, what is the condition for equilibrium? If a body is suspended by a flexible cord, what will be the direction of the cord when there is equilibrium? Why?

What is a plummet or plumb-line? For what is it used? How can you find the center of mass of any body by experiment? Explain the reason for the

method. Suppose that you wished to find the center of gravity of a bat, how could you do so by laying it across the edge of a board? What are the three kinds of equilibrium? Describe each. Give examples of each. If a body rests upon several points, what constitutes its base? What is the condition of stable equilibrium for such a body? Why does a man lean forward when carrying a heavy load upon his back? If you have a heavy weight in one hand, what position do you take? Why? Why does a load of hay tip over so easily if on a side-hill? A coach with heavy baggage piled on top, on a rough road? What do we mean by saying that a thing is top-heavy? Why does a ball placed on a sloping surface begin to roll, while a cube maintains its position? Suppose that a tall tower leans to one side, how much may it lean before it will fall over of its own weight? (Read about the famous leaning tower of Pisa, and of Galileo's experiments there with falling bodies.)

Upon what does the degree of stability of a body depend? Why does a man place his feet well apart when he wishes to plant himself very firmly? Where is the center of gravity in the body of a man? Why does he turn his toes out? Why use a staff when he is old? Why can not a person with his heels against the wall stoop without falling?

Two blocks of wood of equal weight have their centers of mass at equal height; one is shaped like a pyramid and stands on its base, the other is a cube; which is the more stable? Why? A certain wagon is loaded at one time with a ton of iron, at another time with a ton of hay; in which condition is it the more stable? What are common ways of making bodies stable?

Press the head of a needle firmly into the end of a cork, and stick into opposite sides of the cork two forks sloping downward at equal angles. The whole may now be balanced upon the needle's point. Why?

THE PENDULUM.

The Simple Pendulum.—Suspend a stone, or any heavy object, A, from a firm support, Fig. 46. Pull it an inch or two to one side and let it go. It will swing to and fro for a long time. Any object oscillating thus upon a pivot or axis of suspension, by its weight, is properly called a Pendulum; but the term is generally used to refer to small, heavy objects hung by a light suspending cord or wire.

As the pendulum descends from either extreme of its swing, it gains velocity and therefore energy, which it loses again on its upward swing (page 36), and which is greatest at the lowest or middle point. If energy can neither be created nor destroyed, whence comes this energy, and where does it go, the effects of resistance being neglected? Its source is the energy of gravitation; and in losing energy, the pendulum merely restores energy to that source. The process, then, is a periodic receiving and giving back of energy between the stock of gravitational energy and the pendulum. To express the idea in an-

other way, the pendulum has at the extreme of its path a certain potential energy due to its weight and its position, and this potential energy is converted gradually into actual (or kinetic) energy in the descent, and reconverted into potential energy in the ascent. Consider carefully what is meant by *potential energy*, and you will see that the two forms of statement are equivalent.

The simplest possible pendulum would be a material particle hung by a cord without weight. The nearest practicable approach to this is a small, heavy sphere hung by a very light cord or wire. A lead or brass ball suspended by a braided silk cord works best, but small stones hung on twine will answer the purpose.

By the length of a pendulum is meant the distance from the point of suspension to the center of oscillation. For the simple pendulum, the center of mass may be taken as the center of oscillation.

The Laws of the Pendulum are as follows: The time of vibration

I. Is independent of mass or material of pendulum.
II. Is independent of amplitude, if small.
III. Is proportional to square root of length.
IV. Is inversely as square root of g.

These laws will be partly illustrated by experiment.

Experiments with the Pendulum.—Hang up a stone or a metal sphere B by a cord, so that the length of the pendulum (from *b* to center of mass of B) is the same as that of A, as nearly as you can judge. Hold B aside as at *k*, and at the beginning of a minute by a watch or clock let it go. Count one when it reaches *l*, two when it gets back to *k*, three at *l* again, and so on. Just as one hundred is counted, note the number of seconds that have elapsed. This, divided by 100, will give the "time of a single vibration," or swing of B.

Pull A and B aside and let them go at the same instant. You will find that they will keep pace with each other almost perfectly. They have, therefore, the same rate or time of swing.

Make another pendulum C out of a wooden block, hollow tennis-ball, or any other substance, adjusting its length as nearly as possible to equal that of B. Start A, B, and C, swinging at the same instant.

They will keep pace very closely, the slight difference you may observe being due to the fact that the lengths are not exactly equal. These two experiments show that the time of vibration of pendulums of the same length does not depend on the material of the bob.

Adjust the length of B carefully, until by trial it keeps exact pace with A when they are started by drawing aside just one inch. Then draw A aside one inch, and B two inches, and let them go. They will still keep pace. Draw A aside one inch and B three inches. They will still keep pace. This shows that the time of vibration is independent of the distance swung through, which is called the Amplitude of the Vibration. The law holds so long as the amplitude is not very great, but is not strictly true for wide swings. This property is called the Isoch'ronism of the Pendulum, and is an essential fact in the application of the pendulum to the exact measurement of time. It was first noticed by Galileo, who observed that the great chandelier in the cathedral of Pisa swung in equal times without regard to the amplitudes of the swing.

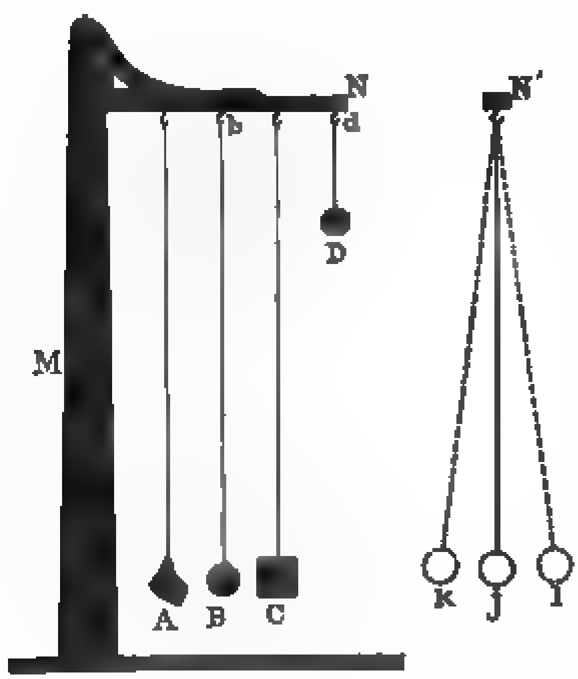


FIG. 46.—FORMS OF THE PENDULUM.—VIBRATION ILLUSTRATED.

Hang a fourth pendulum, D, of a length equal to one fourth that of B. Set B and D swinging at the same instant. You will see that D makes two swings to one of B. The time of one swing of B, then, is twice that of D. The length of B is four times that of D. Therefore, the time of B : time of D = 2 : 1. But 2 : 1 = square root 4 : square of 1. Hence the times of vibration of pendulums of different lengths are proportional to the square roots of their lengths.

Vary the length of B until its time of swing is just one second. Measure as carefully as you can the distance from the point of support to the center of mass of B. It will be a little less than a metre —i. e., about 39 inches. At latitude 45°, sea-level, the length of the seconds pendulum is ·99356 metre = 39·117 inches.

The length l of a simple pendulum to swing in a time t, or

the time of swing for a length l, can, therefore, be found from the formulæ:

$$l = 39{\cdot}117 \times t^2 \text{ and } t = \text{the square root of } \frac{l}{39{\cdot}1}, \text{ for } l \text{ in inches.}$$

$$l = {\cdot}99356 \times t^2 \text{ and } t = \text{the square root of } \frac{l}{{\cdot}994}, \text{ for } l \text{ in metres.}$$

The time of vibration would be less at a place where the force of gravity is greater, because the accelerating force (weight) would be greater for the same mass in the pendulum, which would, therefore, move faster. The pendulum thus affords the most accurate means of determining the value of g in different places.

Application of the Pendulum to Clocks.—The isochronism of the pendulum is utililized in the measurement of time—in subdividing the astronomical unit of time, the day, into hours, minutes, and seconds. Fig. 47 shows the essential parts of the mechanism for this application, and when the following description is studied, some pendulum-clock should be examined by the pupil. The function of the pendulum is solely to regulate the rate of motion of the works, so that the wheels (which carry the hands indicating the time) shall turn at exactly the proper and constant rate.

The source of energy maintaining the motion of a clock is usually elasticity acting by a coiled spring, or gravity acting through "weights" hung on a cord wound over an axle. The work which this energy has to perform is to move the clock-works against their friction, and to keep up the motion of the pendulum, which would otherwise gradually come to rest. Why?

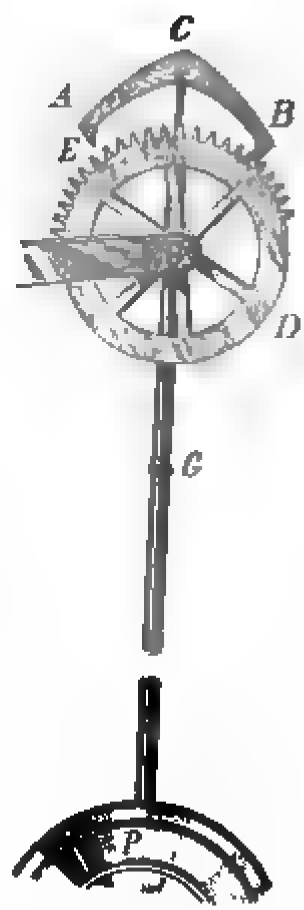


FIG. 47.—ESCAPEMENT OF CLOCK.

A train of wheel-work similar to that of Fig. 58 (page 152) transmits the pressure and motion to a toothed wheel called the scape-

wheel, shown at D E and D' E' (Figs. 47 and 48), and pivoted at F. Let us suppose that this wheel tends thus to rotate right-handedly. A C B is a curved piece of metal called the pallet, having at each end, A and B, a tooth or projecting point. It is fastened at C' to the spindle A' H', which is pivoted at both ends, and to this is also attached the bent rod or wire H' G' G, called the crutch. This whole mechanism is the escapement. The pendulum P hangs from a fixed point I', its upper part being composed of a thin flexible metal strip, I' J', and it passes through the crutch at G G'.

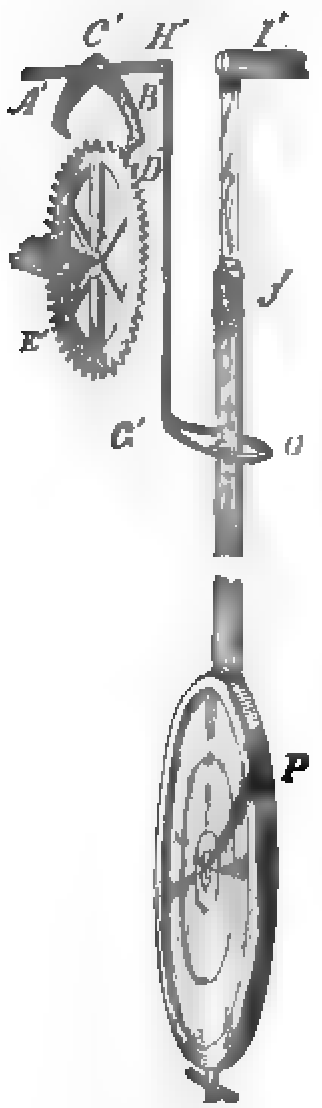


FIG. 48.—PALLET AND CRUTCH.

Let us follow the action, starting with the position shown in Fig. 47. A tooth of the scape-wheel is pressing against the pallet-tooth at B, owing to the pressure of the spring or weights, and the wheel is thus held from moving. The pallet-tooth A is free of the wheel. The crutch and pendulum are at one extreme of the swing, and will therefore now begin to swing back. When the pendulum becomes about vertical, the pallet will have turned so that its end A will have descended into the space between two teeth at E, and the end B will have risen just enough to release the scape-wheel tooth. The scape-wheel will, therefore, jump forward until the following tooth strikes the pallet at A, advancing thus by about the space of half a tooth. The pendulum, continuing its swing, will reach its right-hand extreme, and will then turn and swing back, the pallet at A presently releasing the scape-wheel, which then advances another half-tooth until stopped by the pallet at B. This process goes on continuously, the scape-wheel advancing a whole tooth for each double-swing of the pendulum.

The energy necessary to overcome air resistance, etc., and thus to maintain the pendulum in motion when once started, is supplied to it from the scape-wheel through the pallet and crutch. Start again with the first position of Fig. 48. The wheel is then pushing up the pallet at B',

owing to its pressure on the sloping pallet surface, and this, of course, pushes the crutch, and the crutch in turn the pendulum, to the right, adding to their energy. Such action continues until the pallet releases at B′ and engages at A′. From the right-hand end of the swing downward, the wheel similarly pushes upward the end A′ of the pallet.

The Balance-Wheel replaces the pendulum in watches and some clocks. It consists of a pivoted wheel which swings to and fro on its axis in equal times, owing to the elasticity of a spring attached to it.

QUESTIONS.—What is a pendulum ? What is meant by a simple pendulum ? What maintains the motion of the pendulum ? What causes it to come gradually to rest ? What is meant by the length of a pendulum ? State the laws of the pendulum. Show how to demonstrate these laws by experiment. What is meant by the isochronism of the pendulum ? What is the length of a pendulum beating seconds ? Beating half-seconds ? Beating quarter-seconds ? How may the pendulum be used to measure the variations in weight at different parts of the earth's surface ? Explain the application of the pendulum to clocks.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Why is it easier to carry the same amount of water in two pails, one in each hand, than in a single pail ?

Can you explain the object of feathering your oars while rowing ?

How is our earth kept in its path about the sun ?

In the latitude of New York, a seconds pendulum is about 39 inches long. How long must one be to vibrate once in seven seconds ? How long to vibrate four times in a second ?

At the equator, a pendulum 39 inches long vibrates once in a second. How long must a pendulum be to vibrate once in half an hour ?

Would a plumb-line on a ship's deck under the rock of Gibraltar hang perpendicularly ? Why ? Could you easily detect the variation ?

Is there a place between the moon and the earth where a body would have no weight, and would not fall in any direction ? Explain.

Would you weigh more or less on the moon than on the earth ? Why ? Could you jump farther on the moon ?

On what principle may a load of stone pass safely over a hill-side where a load of hay would be overturned ?

Have you ever noticed persons bend forward in rising from a chair ? How do they change their center of gravity in so doing ? Why do you instinctively lean back when descending a steep hill ? Do you really incline your body out of the vertical in so doing ?

Does a trotting horse raise both feet on the same side at the same time ? Why ?

When a man is fishing with a heavy sinker in a strong current, his line assumes

a slanting position. Can you construct a diagram illustrating the nature and action of the forces in operation?

Is the velocity of every particle of mud on a revolving carriage-wheel the same? Why does the mud fly off from the felly and not from the hub?

How can you determine whether a wall is exactly vertical?

Why is your student's lamp made so heavy at the base?

Two pendulums at Jacksonville, Fla., vibrate in 40 seconds and 10 seconds. How many times longer is one than the other?

Explain the principle on which his fly-rod, held horizontally, greatly aids an angler in maintaining his balance on a thin tree-trunk or a rounded log.

FRICTION AND MACHINES.

NATURE AND LAWS OF FRICTION.

Friction opposes Motion.—Draw your hand across any surface, push a pile of books along the table-top or a chair across the floor—in short, cause any two solid surfaces to rub together; you will find that to keep up continuous motion you must do work. This is true even if a uniform velocity is maintained, in which case the object is not storing up or giving out kinetic energy. You are moving the body uniformly against a resistance. This resistance is at the rubbing surfaces, and is called Friction.

What is the nature of frictional resistance, and what becomes of the energy used up in doing work against friction? The second question has been answered by showing (page 40) that the rubbing surfaces become hot. The energy is transformed into heat. Of the nature of the resistance caused by friction, we may form an idea in the following way:

No surface is perfectly smooth. Even polished surfaces, when viewed through a glass, appear scratched or uneven. The irregular lines *a b c d* (Fig. 49) may represent a magnified section of the smooth, rubbing surfaces of two bodies, A and B. Notice how the irregularities of these surfaces interlock. Thus, at *a*, *b*, and *d*, for instance, when moving over B in the direction of the arrow, A would experience a resistance owing to the backward elastic pressure of the

points of B. If, then, A is pulled along, it must slide upward at these various points and pass over them. This is accomplished partly by a rise of the whole body A, partly by compressing or bending the projections at the points of contact. As A moves along, a multitude of such little actions occur, which are like so many slight blows. In this way, vibrations are set up in the particles of the rubbing surfaces, and the energy of these constitutes the heat produced by the rubbing.

FIG. 49.—ILLUSTRATING FRICTION OF RUBBING SURFACES.

It is thus not difficult to conceive how the resistance of friction is due to the interlocking of roughnesses of surface. If the smoothness of the surface could be made perfect, two clean rubbing surfaces of the same substance would not differ from two parts of the same body separated merely by an imaginary plane. The only interlocking then would be due to the vibration of the molecules across that surface, which of itself would be enough to cause very great friction.

Laws of Sliding Friction.—Let A (Fig. 50) be a block of well-planed wood 2 by 4 by 8 inches, sliding on a smooth horizontal board C. Let B be a pulley turning with little friction, over which runs a cord attached to A at E and carrying a pan for weights below. A spiral spring fastened to the table and by a cord to the pan checks the descent of the latter somewhat gently, and thus prevents the spilling of the weights. Put sand or shot into the pan until, on tapping the block A with the finger, it will start and keep up its motion, but not be accelerated. Note the weight of pan and contents together and call it w_1; also the weight of the block, and call it W_1. Then w_1 is called the amount of "friction of motion" of A upon C under the pressure W_1.

EXPERIMENTS.—The amount of this friction depends on the amount of the pressure W_1. Put a weight upon A so that the pressure is doubled—i. e., is 2 W_1. Increase the load in the pan until motion is again just kept up. On weighing the pan and contents, you will now find it very nearly 2 w_1. If you make the pressure 3 W_1, the pan-load will be found 3 w_1, and so on. Hence, *the friction of motion*

is proportional to the pressure with which the surfaces are held in contact.

Remove the load from A and the pan. Turn the block over upon a larger or smaller side, keeping the cord E B still horizontal. Load the pan until motion is just maintained. The load will be found equal to w_1 or nearly so. It would be exactly equal if the surfaces were of equal smoothness. Thus *the friction is independent of the area of the rubbing surfaces.*

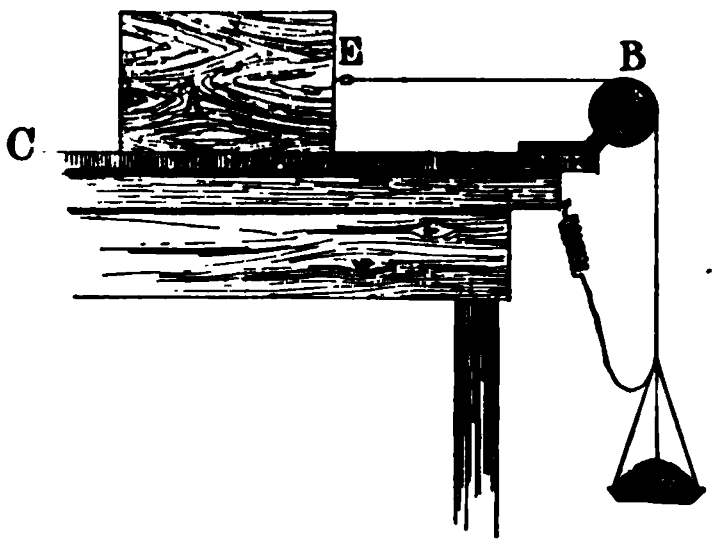


FIG. 50.

Put a sheet of rubber upon one face of A. Find w by trial. It will be quite different from w_1. Call it w_2. *The friction depends on the nature of the rubbing surfaces.*

The quotient $\frac{w}{W}$ is called the *coefficient of friction* for the particular surfaces rubbing. Thus $\frac{w_1}{W_1}$ = coefficient of friction of motion for wood (of kinds used) on wood; $\frac{w_2}{W_2}$ = coefficient for rubber on wood, etc. These coefficients enable one to find what the friction would be for a given pressure between the surfaces. They are approximately constant for any given substances.

The friction is often stated to be independent of the speed at which the surfaces are moving on each other. This is by no means generally true, but for some substances is nearly so where the speeds change but little from a given amount.

All three of the above laws are only rough approximations. Friction varies so greatly, with slight differences of condition of the surfaces, that measurement of it appears inexact and unsatisfactory.

Friction of Repose.—Adjust the load in the pan until it is just sufficient to start A from a state of rest. You will then find it decidedly greater than that necessary to maintain motion. Here we have the Friction of Repose, or, more

properly, Starting Friction. It varies with the substance, the time during which the surfaces have been in contact, and many other conditions.

Friction of Gases and Liquids.—Lay a clean plate of glass on the table. Place upon it another plate of about the same size. Press the two firmly together for a moment. Then let go, and slide the upper plate over the lower by pushing horizontally against the edge with your finger. Bear in mind how hard you have to push. Lift off the upper plate, lay it gently down again on the under plate, and immediately slide it by a side push. Note how much more easily it slides. This is because the glass surfaces are not so nearly in contact as before, but are kept apart by the film of air between them; and the friction is that of the layers of air parallel to the plates moving over each other. Such friction is much smaller in amount than the solid-surface friction. When the upper plate settles down by its weight, forcing the air out, the friction increases.

Remove the upper plate, and apply a layer of water or oil to the lower one. Put the plate on again lightly, and notice how easily it slides. Here the friction is that of layers of water or oil parallel to the plates. The friction of some liquids is less than that of others, and the same is true for gases; in all cases, it varies with temperature.

The use of oil for greasing or "lubricating" rubbing surfaces (axles, bearings, etc.) is familiar to you, and is simply a process of making the lesser friction of the oil or other lubricant replace the greater friction of the dry surfaces. The object is to avoid the injury to the surfaces by the grinding and polishing of the dry rubbing, and also to do away with the waste of energy required to overcome such friction.

QUESTIONS.—Give examples of friction. Show what the nature of frictional resistance is. Into what form is the energy used in overcoming friction changed? Explain how this transformation is made. If rubbing surfaces could be made perfectly smooth, would there be any friction? Why? State the laws of sliding friction. Describe a method of proving each.

What is meant by the coefficient of friction of motion? If a pull of 5 pounds is

required to keep a body just moving over a horizontal surface, the weight of the body being 25 pounds, what is the coefficient of friction of motion?

If the coefficient of friction of motion of wood on wood is 0·3, what force would be necessary to draw a body weighing 50 pounds along a horizontal surface?

If a force of 2·1 pounds was found necessary to draw a block of wood over a surface where the coefficient was 0·3, what was the weight of the block?

Is friction independent of the speed of motion? How may the friction of gases and of liquids be experimentally illustrated? Explain the action of oil and other lubricants. What is their object?

MECHANICS.—THE SIMPLE MACHINES.

Mechanics, in the strict sense of the word, is the Science of Machines and the art of constructing them. It is quite common, however, to include under this head all the earlier portions of physics, as far as the special branches of Heat, Light, Sound, etc.

Machines.—Any apparatus or instrument designed to transform or transmit energy for the purpose of doing desired work is called a Machine.

Suppose, for example, that we have a supply of coal, and wish to move a train of cars from Boston to New York. The coal represents a certain amount of heat-energy, which can be obtained by burning it. In order to move the train the required distance, it is necessary that a certain amount of work shall be done. The mere production of the heat-energy by burning the coal will not move the train. How, then, can the object in view be accomplished? One method is by the use of a steam locomotive. This takes up the heat-energy of the coal, and, by various processes and contrivances, transforms it into mechanical energy, applied to its wheels in such a way as to perform the desired work. The locomotive, then, is an example of a machine.

Machines are of various degrees of complexity, from that of a simple wooden rod or knife-blade to that of the most intricate loom. In our early experiments, where one ball was made to impart energy to another by collision (page 31), there was no necessity for the intervention of a machine, because the mere collision of the elastic balls served to bring about the transference of the energy. But suppose the ball A had been moving away from B, or in

some direction in which it would not strike B; then, to transfer the energy from A to B, we should have required some apparatus through which such energy could be transmitted. For example, the balls might have been connected by a rope passing over a wheel in such a way as to make B move in the desired direction. Then this rope and wheel would have constituted a very simple machine.

Where the energy is to be changed in form, instead of being merely transferred, the machine becomes somewhat more complicated, as where heat-energy is to be transformed into mechanical energy in a steam-engine (page 286), or mechanical into electrical energy in a dynamo-electric machine (page 522). But the complication of machines arises chiefly from the complexity of the kind of work to be done, or the perfection with which it must be done, rather than from the nature of the process of transformation.

Whatever its form, and however perfect or complex it may be, *a machine merely transfers and transforms, but can never generate, energy.* In other words, the work done, or energy given out, can never be more than the energy taken up by the machine.

Efficiency of Machines.—An ideal machine would give out as useful work all the energy applied to it. In practice, owing to friction, bending, and certain laws of the availability of energy, no machine is ideal. Actual machines, then, give out less useful work than is equivalent to the energy imparted to them. The "lost" energy is merely changed within the machine into forms which are not of service for the purpose of the machine. Thus, friction causes some energy to be transformed into useless heat, and is one of the chief sources of loss in most machines.

The ratio of the amount of useful work given out by the machine to the total energy put into it is called the *efficiency* of the machine. For instance, if a certain machine had applied to it 10 foot-pounds of energy, and, owing to friction, converted 2 foot-pounds into heat, and wasted 1 foot-pound in other ways, it could give out only 7 foot-pounds.

Its efficiency as a machine would then be $\frac{7}{10}$, or 70 per cent.

The Simple Machines.—There are a few machines so simple in form and principle that they are called the Simple Machines. The more complicated machines are composed largely of combinations and modifications of these. The simple machines are sometimes called *the mechanical powers* They are the Lever, Wheel and Axle, Inclined Plane, Wedge, Screw, Pulley, and Knee.

In studying the principles of these machines, we shall consider them as ideal—that is, as if they were without mass and weight, and as if they worked without friction, bending, etc. In actual practice these things, of course, do exist, and must be taken into account, but they do not affect the principles of the machines.

The Lever.—To move heavy objects, such as rocks, etc., the workman uses a crow-bar or pry. This is a bar or rod, usually of iron. One end of the bar is placed under the rock to be moved, as at B (Fig. 51). Beneath this end, at F, is set a stone or other small object, and then the workman presses down at A with his hand or by bearing on with the weight of his body. By this means he is able, with a comparatively small force applied at A, to lift a very heavy object at B. A bar so used is one form of Lever.

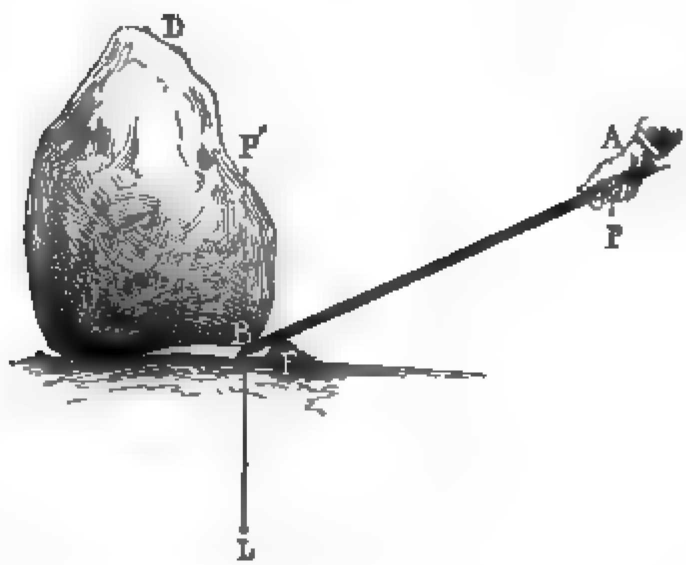


FIG. 51.—ILLUSTRATING THE ACTION OF THE CROW-BAR.

EXPERIMENTS WITH THE LEVER.—Obtain a strong stick five or six feet long, or a crow-bar, and try to move a heavy object as shown in Fig. 51. Put F at first half-way from A to B, and notice the pressure

required at P to lift D or to tip it up. Place F nearer and nearer to B, and observe how the force required at P is less and less as A F becomes greater in proportion to B F. You will be surprised at the amount you can lift by making B F very short in proportion to A F. Your bar is a true lever.

The force P at A will be called the working force or the *power*. The force L at B will be called the *load*. The point F of support, in other words the pivot, will be called the *fulcrum*. In principle, *a Lever is any solid pivoted rod by means of which a force at one point is made to balance a load at another point.*

Kinds of Levers.—Levers are generally classed as of three "orders"; but this classification is of no special importance, since the law is the same for all. The first order (Fig. 52) is where the fulcrum is between the two forces (power P and load L); the second, where the load is between the power and the fulcrum; the third, where the power is between the load and the fulcrum.

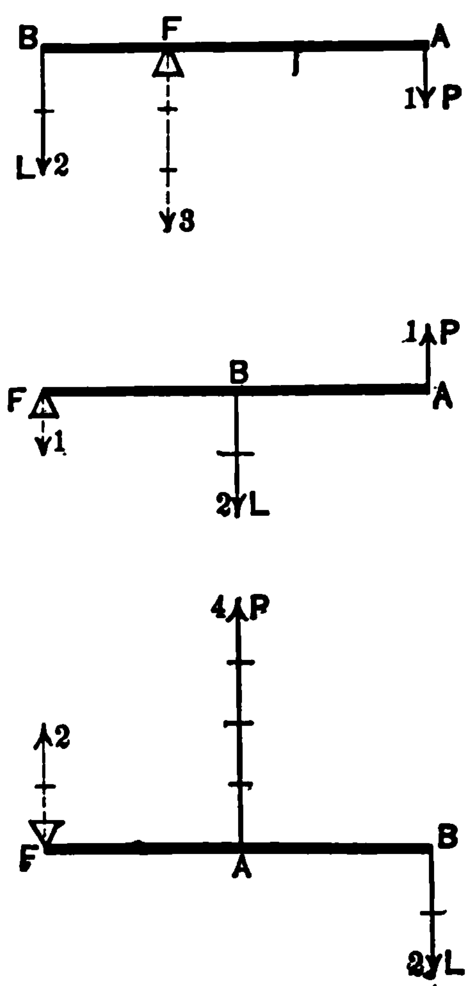


FIG. 52.—THREE ORDERS OF LEVERS.

As an aid to the memory, observe that in the three orders the initial letters F L P of the middle points—fulcrum (1), load (2), power (3)—stand in alphabetical order.

The Principle of the Lever.—In Fig. 52, for each order, we have the power P working at A, the load L at B, and the fulcrum at F. The arrows represent the amount and directions of the forces L and P, and the pressure on the fulcrum F, starting with the same load L in all cases, and with P and L at right angles to the lever, which is represented as straight and horizontal for simplicity.

We have, then, in each case two forces, P and L, tending

to turn the lever about the fulcrum F. The moment of the power is $P \times A\,F$, that of the load is $L \times B\,F$. For equilibrium, these two moments must be equal and must be in opposite directions (page 112). Hence, to balance a given load L on a lever, we must have $P \times A\,F = L \times B\,F$ or $P\dfrac{A\,F}{B\,F} = L$. The ratio $\dfrac{A\,F}{B\,F}$ is called the *leverage*. The law of the lever may be stated thus:

For equilibrium on a lever, the moment of the power must be equal and opposite to the moment of the load. Or the power into the leverage must equal the load, and the direction of the moments must be opposite.

Illustrative Examples.—A man wishes to raise a stone weighing a ton. He uses a horizontal lever of the first order, and is able to make the distance from power to fulcrum 4 feet, and that of load to fulcrum 6 inches. How much force must he exert at P? $P \times A\,F = L \times B\,F$ $\therefore P \times 4 = 2000 \times 0{\cdot}5 \therefore P = \dfrac{2000 \times 0{\cdot}5}{4} = 250$ pounds.

What was his leverage? $\dfrac{A\ F}{B\ F} = \dfrac{4}{0{\cdot}5} = 8$.

Suppose he weighs 150 pounds, could he lift the rock by his weight with this leverage? No; because he requires 250 pounds, and can obtain only 150 pounds. Of course, he might add to this weight by using other rocks.

What leverage must he have to be able just to balance the rock? $P \times \text{leverage} = L \therefore 150 \times \text{leverage} = 2000 \therefore \text{leverage} = \dfrac{2000}{150} = 13{\cdot}3$.

If, then, his lever is 4·5 feet long, where must the fulcrum be placed? $\dfrac{A\ F}{B\ F} = 13{\cdot}3 \therefore \dfrac{A\ F + B\ F}{B\,F} = \dfrac{13{\cdot}3+1}{1} = \dfrac{14{\cdot}3}{1}$. But $A\,F + B\,F =$ whole length of lever $= 4{\cdot}5$ feet $\therefore B\ F = \dfrac{4{\cdot}5}{14{\cdot}3} = 0{\cdot}31$ ft. or 3·7 inches $\therefore A\ F = 4{\cdot}5 - 0{\cdot}31 = 4{\cdot}2$ feet.

Pressure on the Fulcrum.—In the lever there must always be a pressure on the fulcrum. If the power and load are parallel, as in Fig. 52, the pressure on F will be found by the laws for the resultant of parallel forces. If P and L are

not parallel, the pressure on F must be found by the parallelogram of forces.

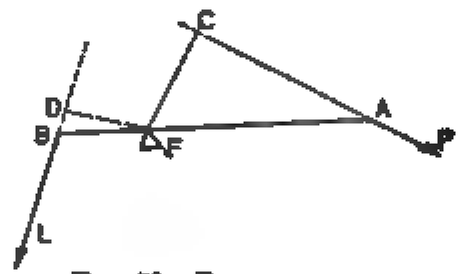


FIG. 53.—POWER APPLIED OBLIQUELY.

Oblique Forces and Bent Levers.—If the lever is straight, but either P or L is not at right angles to it, then the moment must be found by dropping a perpendicular from F upon its line of action. For instance, in Fig. 53, equilibrium would occur only when $P \times FC = L \times FD$.

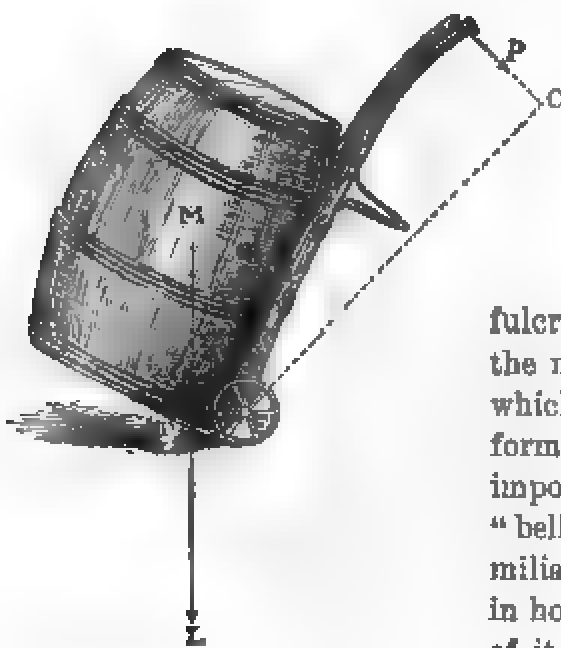


FIG. 54.—THE HAND-TRUCK.

In general the lever is not straight, but curved or angular. This makes no difference in its principle. The truck (Fig. 54) is a form of lever; the fulcrum is the axle of the wheels, and the moments are $P \times FC$ and $L \times FD$, which must be equal and opposite. A form of bent lever which has many important applications is called the "bell-crank lever" because of its familiar use to turn corners in bell-wires in houses. Find one, make a drawing of it, and explain its principle.

Among the common forms of the lever may be mentioned the pump-handle, well-sweep, shears and scissors, claw-hammer when used to draw nails, walking-beam of steamboat, oar, forceps, tongs, the steelyard, and all movable bones of the bodies of men and animals. Explain from Fig. 55 how the forearm acts as a lever when raising a weight in the hand. To what order does it belong?

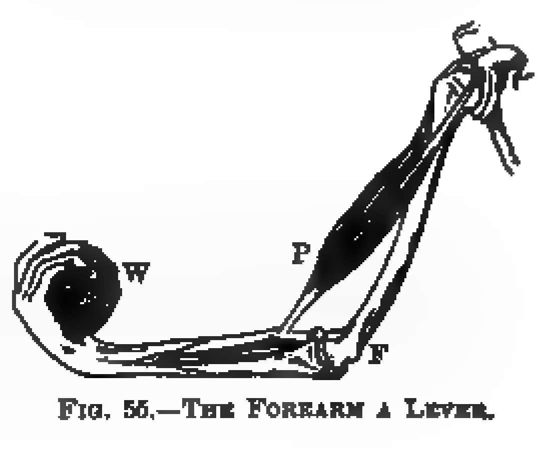


FIG. 55.—THE FOREARM A LEVER.

Work done with Lever.—Take, as an example, a lever of the first kind,

A B (Fig. 56), and suppose P and L to remain always at right angles to the lever as it moves. If the end A be moved by P until it has passed on to any point C, it will have passed through a distance A C along the arc of a circle with F as a center. The end B will at the same time pass through a distance B D along another arc whose center is also at F. By geometry, A C : B D = A F : B F. But, by the law of the lever, A F : B F = L : P $\therefore$ A C : B D = L : P $\therefore$ P$\times$A C = L$\times$B D. But, as shown on page 97, work is the product of the force into the distance through which the body moves; therefore P$\times$A C = work done by P, and L$\times$A F = work done against L. Hence, *the work done upon the lever by the working energy is equal to the work done by the lever against the load.*

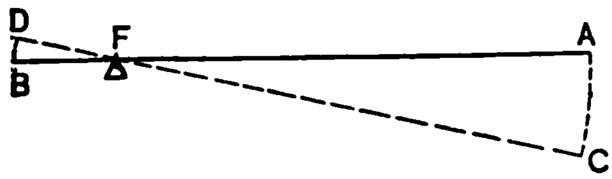


FIG. 56.

This fact is also a necessary and direct consequence of the principle of the conservation of energy. The law of the lever might equally well be deduced by assuming that principle and working backward from it, as will be done in the case of some other machines.

Actual Lever.—The demonstrations have shown the principle of the ideal lever. In the actual lever we must allow for the mass and weight of the lever, for friction, for the fact that in most cases the forces change direction and therefore leverage as the lever moves, and, finally, for the energy required to set in motion the object moved.

Perpetual Motion.—It has been stated that no machine can give out more energy than is put into it; or, in other words, can do more work than is done upon it—this being a necessary consequence of the principle of conservation of energy. If any machine could give out more energy than it received, then of that energy a part might be utilized to run the machine itself, and the rest stored up for future use. Thus the machine could keep itself going, and at the

same time supply energy. This would manifestly imply a generation of energy; but we have proof on every hand that energy can not be generated, and the supposed case must, therefore, be an impossibility. Even a machine which will keep itself running without any outside supply of energy is also an impossibility, because it is physically impossible that there should not be some energy wasted—i. e., turned into unavailable forms—in every machine. Hence a machine with an efficiency of unity, or one hundred per cent, is impossible. Such machines are commonly spoken of as perpetual-motion machines, obviously because they could keep themselves going perpetually.

Schemes for perpetual-motion machines, and for machines that would produce more energy than was required to run them, were much more common before the doctrine of energy was well understood than at present. That "you can not make something out of nothing," is as true of energy as of matter.

Mechanical Advantage.—Although there can be no gain of energy by any machine, but must always be more or less actual loss, yet there may be a great *advantage* derived from its use. We are able to accomplish things with the aid of machines which we could not do without them, because the machines enable the energy at our command to do work for which it would not be available if directly applied.

Take, for example, the lever. Suppose that a man who can lift only 100 pounds wishes to raise a rock weighing 1,000 pounds. It is ten times as much as he can possibly lift. He has energy enough to lift the rock to any desired height, for if the rock were in ten equal parts he could lift each separately to that height, thus doing the work, and the mere separation of the rock into parts has not increased his energy. But he can not exert force enough to lift the rock as a whole against gravity—that is, he can not exert force enough to balance the weight of the rock. Give him a lever, however, with a leverage of 10 to 1, and he can, by exerting 100 pounds on the long end, produce 1,000 pounds at the short end, and thus balance the weight of the rock. Then, by keeping up the pushing (ten times as far as the load moves)

he can perform the work necessary to lift the rock to the desired height, doing no more work than that required to lift the ten separate parts. It is thus apparent that, although he has gained no energy, the lever has made his energy available for the purpose at hand, and therein is the "advantage." An advantage thus gained by means of a machine is called a Mechanical Advantage.

Think over the various forms of lever and of other machines as you come to them, and see wherein the mechanical advantage consists, and how there is no gain, but rather some loss of energy. This is the key to the intelligent understanding of all machines.

QUESTIONS.—What is meant by the term Mechanics in its strict sense? How is it quite commonly employed? What is a Machine? Give examples. Why do we have to use machines? Can machines generate energy? If not, of what use are they? How can we generate energy? What is meant by an ideal machine? Why must any actual machine be inferior to an ideal machine? What becomes of energy wasted by a machine? In what way is much of the wasted energy used up? What is meant by the efficiency of a machine?

A certain machine gives out as useful work two thirds of the energy applied to it; what is its efficiency? A certain machine wastes one quarter of the energy applied to it; what is its efficiency?

What is meant by the "simple machines"? Name those described in this chapter. Why do we consider first ideal machines in studying the laws and principles of the simple machine?

Describe the Lever. What is meant by the power? the load? the fulcrum? Describe the three orders of lever. State the rule or law of the lever. Deduce this law. Define leverage.

A man wishes to pull upward on a chain with a force of 500 pounds, and has a horizontal lever of the first order 11 feet long; what pressure must he use if he places the fulcrum one foot from the load? What would then be his leverage? If he can use but 25 pounds pressure, what leverage must he have? Where must the fulcrum be placed? Solve the same problems with the lever of the second order. In the first problem, how much would be the pressure on the fulcrum? Suppose that the man pressed at an angle of 45° to the lever instead of at right angles to it, how much pressure must he exert? Suppose that both power and weight were vertical, but that the lever was inclined at 45° to the horizontal, how much pressure would be required? Why is it usually best to push as nearly at right angles to the lever as possible?

What is the relation between the work done upon and by an ideal lever? Between the energy put into it and that given out? Deduce the law of the lever, starting with the principle of the conservation of energy. If, in the first problem with the lever, the man was obliged to put in one half as much more work on account of friction as was necessary to balance the load, how much must he increase the moment of the power? If the leverage is kept the same, what pressure must he exert? If the pressure is kept the same, how much must he increase the leverage? What would be the efficiency of this lever? Show how each of the examples mentioned on page 147 is a lever, and of what order.

If a machine could give out 110 foot-pounds for every 100 foot-pounds supplied, what would be its efficiency? Would such a machine be possible? What would

it be called? Why? If possible, would such a machine be valuable? Why? How do we know that such a thing is impossible? What is meant by mechanical advantage? Give an example.

WHEEL AND AXLE.—INCLINED PLANE.—WEDGE.

Wheel and Axle.—Let C represent a wheel around which is wound a cord carrying a weight P. Let E D represent the axle to which C is fastened, turning in the supports. A side view is shown at A B F, on the right.

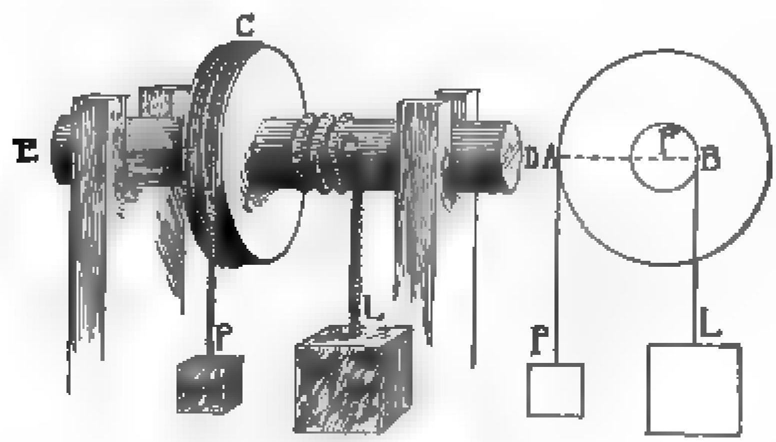


FIG. 87.—PRINCIPLE OF THE WHEEL AND AXLE.

Around the axle is wound a rope at G, carrying a larger weight L. In this machine, P is the power and L the load, just as in the lever; by examining closely you will see that the wheel and axle is merely a modification of the lever. The fulcrum is at F, the axis of rotation; the power is applied at A, at the end of a lever-arm A F; the load at B, at the end of a lever-arm B F. The moment of the power is P×A F; of the load, L×B F. As the power descends the cord unwinds, and P thus acts always with a constant arm. Similarly, as P descends L ascends, the rope winds up, and L acts always with a constant lever-arm B F.

The wheel and axle is merely a device for making the lever continuous in its operation. The laws in the case of this machine are the same as those of the lever.

Modifications of the Wheel and Axle.—The wheel is often replaced by a crank, the power being applied to the

handle of the crank, either by hand or by machinery. Such a device is often used for raising a bucket of water from a well; and most hoisting apparatus, as cranes, derricks, etc., are further modifications of the wheel and axle, as are also the capstan, the pilot-wheel, and the windlass.

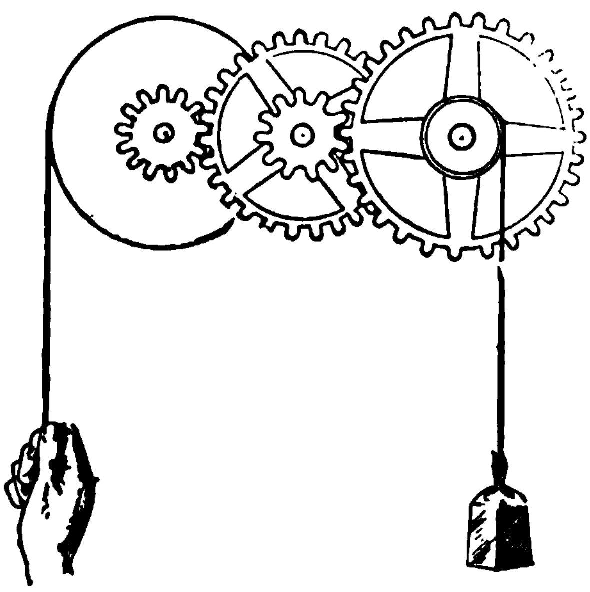


FIG. 58.—TRAIN OF WHEELS IN GEAR.

Gear-wheels act on the same principle. In Fig. 58 the hand represents the power pulling a cord upon the circumference of a wheel. On the axle is a small toothed wheel which "meshes" into a larger one. This in turn carries a small one engaging with a larger wheel, and so on. The second large wheel turns more slowly than the first; the third, more slowly than the second. Thus the load winds up on the axle of the third wheel much more slowly than the power descends. Such an arrangement is called a train of wheels.

Suppose that the power descends 10 inches while the load rises 1 inch; then $P \times 10 = L \times 1$, and $L = 10 P$—that is, the power can balance ten times itself. In general, let a denote the distance through which the power moves, and b the distance through which the load moves in the same time; then $P \times a = L \times b$.

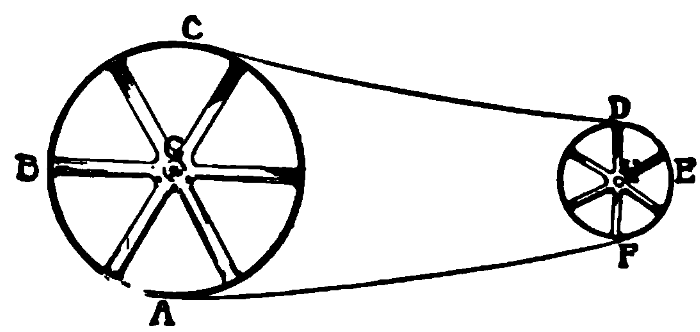


FIG. 59.—ILLUSTRATING THE BAND.

Another modification of the wheel and axle occurs in the transmission of power by belting. Let A C represent a large pulley running on a shaft G, and D F a small pulley running on a shaft H. The belt is continuous, and, starting from A, passes around B C D E F back to A. If the circumference of A C is twice that of D F, and the former drives the latter, then D F must turn twice as many times a minute as A C. Any other pulley attached to the shaft H would also turn twice as fast as A C. A large pulley on this shaft might be belted to a small one on

another shaft, which would then move still faster. The same arrangement may be used in reverse order to reduce speed.

Inclined Plane.—Any flat surface which is not horizontal forms an Inclined Plane. A flat board more or less tipped, a "pitched" roof, a smooth hill-side, a grade on a road or railway, the sloping surface of a sand-bank, are examples of inclined surfaces more or less approaching to perfect inclined planes. In machinery, we find inclined planes in modified forms in the eccentric, cam, wedge, screw, propeller-blade, windmill fan, etc.

The amount of inclination of the plane is called its *grade* or *slope*, and is measured by the amount that the plane rises from a level in a given horizontal distance, or by the ratio of the rise to the horizontal distance. For instance, if a road has such a steepness that it rises 5 feet vertically in a distance of 100 feet horizontally, then its grade or slope is said to be 5 feet in 100 feet, or simply 5 in 100, or 5 per cent. The grade may also be expressed by the angle (measured in degrees) between the surface and the horizontal.

Let A B represent the board of the apparatus of page 78, supported in an inclined position by an upright. Then the grade or slope of the inclined plane A B would be the amount $d\ e$ that the board rises in a horizontal distance $a\ e$, or the ratio $d\ e : a\ e$. If $d\ e = 2$ feet and $a\ e = 5$ feet, then the grade is 2 feet in 5, or 4 in 10, or 40 per cent.

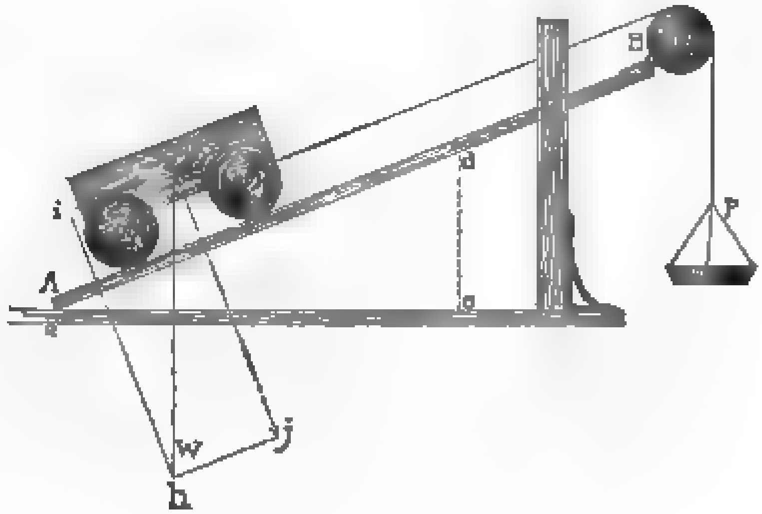


FIG. 60.—INCLINED PLANE.

Suppose the cart to be placed in the position shown in Fig. 60, and loaded so as to make W, the weight of cart and load, equal to 10 pounds. This weight may, for present purposes, be

considered as acting vertically downward through the center of mass, g, of cart and load. Let $g\,h$ represent this weight. Draw through g the lines $g\,i$ parallel to the plane and $g\,j$ perpendicular to it. Resolve the force W into components in these two directions, by completing through h the parallelogram. Then the two forces, $g\,i$ and $g\,j$, will be equivalent in effect to W. Thus, owing to the weight, there is a force represented in amount and direction by $g\,i$ pulling the cart downward along the plane, and another simultaneous force, $g\,j$, perpendicular to the plane. The force $g\,j$ can not result in motion, since it is wholly counterbalanced by the resisting pressure of the plane. The force $g\,i$ will produce motion down the plane, unless counterbalanced. The cart will, therefore, run down the plane. But notice that the force $g\,i$ is less than W; hence the acceleration down the plane will be much less than if the cart were allowed to fall freely in a vertical direction.

To hold the cart in equilibrium we must, then, apply a pull along the cord in amount equal to $g\,i$. Observe that, if the grade is made greater, the amount of $g\,i$ will be greater for the same load W; hence $g\,i$ increases as the grade increases. A horse pulling a wagon up a hill has to pull with more force as the slope grows steeper.

The Friction of any Body moving over a Surface is proportional to the pressure against the surface. Notice that $g\,j$ diminishes as the pitch increases, and is always less than W. Hence, the steeper the pitch, the less the work against friction.

To pull the Cart up the Plane, then, by a force parallel to the plane, we must apply energy at a sufficient rate to produce, first, force enough to balance the backward pull $g\,i$, and, in addition, enough more force to do the work of friction necessary to move the cart at the desired speed, and also to accelerate the cart if it is to be started from rest or is to be moved with accelerated motion. This is the energy supplied by an engine drawing a train up a grade, or by a person in walking up-hill.

Work on Inclined Plane.—Force parallel to Length.—Suppose the cart to be pulled up the length ad of the plane by a force P parallel to ad. The work performed by the energy which produces the force P will be

measured by $P \times ad$. The work done upon the cart, if friction be neglected, consists in raising it through a distance equal to $e\,d$ against the resistance W of its weight, and is therefore $W \times ed$. These two quantities must be equal to each other by the principle of the conservation of energy. Therefore $P \times ad = W \times ed$, or $P : W = ed : ad =$ height : length. This would be the least value of P for a given weight W.

In any actual case, the work done must be greater than $P \times ad$, and therefore the actual working force must be greater than P by an amount necessary to do the work of friction, of acceleration, etc.

Force parallel to Base.—In its application to machinery, the inclined plane is used to raise or force apart bodies or portions of machines. For instance, the rod A B, running in the guide C D and pressing downward with a force F, may require to be lifted. This may be done by forcing under it the inclined plane $a\ d\ e$ sliding on the surface G H. Let the pressure be exerted by a force P parallel to the surface G H. How great must this force be in order to push A B backward against F?

Suppose the plane moved along so that the whole length $a\ d$ is gradually pushed under A B, which will thus be lifted against F through a distance equal to $e\ d$. The work done upon it will then be $F \times ed$. The work done by P will be $P \times ea$, and this, friction being neglected, must be just equal to $F \times ed$. Therefore, $P \times ea = F \times ed$ $\therefore P : F = ed : ea =$ height : base. This would give the minimum value of P. In an actual machine, P would be enough greater to do the work of friction, acceleration, etc.

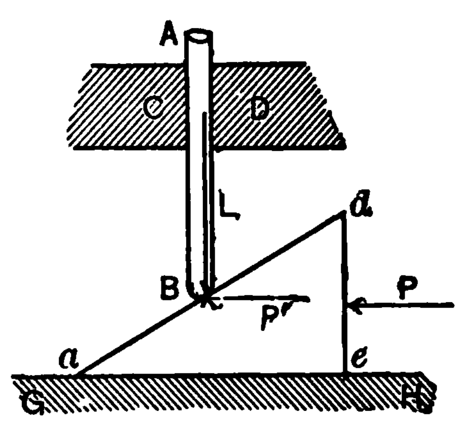


FIG. 61.

Angle of Repose.—If any body is allowed to roll or slide down a grade, then gravity furnishes the energy to do the work of friction and acceleration. In this case it will be seen that, since friction is a retarding force, and $g\ i$ diminishes toward zero as the pitch of the plane is made

smaller, there will be a certain pitch at which the force $g\,i$ will be just equal to the friction. At this pitch the body will continue to roll or slide at a uniform velocity when started, because under balanced forces and therefore following the first law of motion. If the angle is further diminished, the force $g\,i$ will become less than the friction, and the body if started will soon stop. The angle at which this result is just reached is called the Angle of Repose.

Pour sand slowly out of a pail or beaker upon the table. It will pile up steadily at first; but soon the slope of the sides of the pile will be equal to the angle of repose for sand, and any more sand poured upon the top will slip down over the sides to the foot of the pile, and the angle of the sides will be maintained nearly constant. Or build up a high pile of moist sand, and let it dry. Jar it a little and it will begin to fall and continue falling until the slope of the sides is the angle of repose of the dry sand. For this reason, at the foot of sand or gravel banks and rocky cliffs, the natural piles of fallen material will be seen to have quite a uniform incline. The slopes where a railroad-bed has been constructed by filling in, or by cutting through gravel or sand, illustrate the angle of repose.

Experiments should be tried by the pupil in measuring the angle of repose for various substances, as for blocks of different material on a board arranged to tip at various angles; for gravel, shot, etc. The angle of repose of water is zero—that is, the surface of a mass of water is perpendicular to the line of action of its weight, and is therefore what we call level; yet the surface of water is not a plane, but a part of a sphere with its center at the earth's center.

The Wedge.—Fig. 62 shows the Wedge in its simplest form. The action here is merely that of the inclined plane. The solid *ade* in Fig. 61 is really a wedge, and its upper and under surfaces are planes inclined to each other. The axe, the chisel, the knife, the diamond used in glass-cutting, are applications of

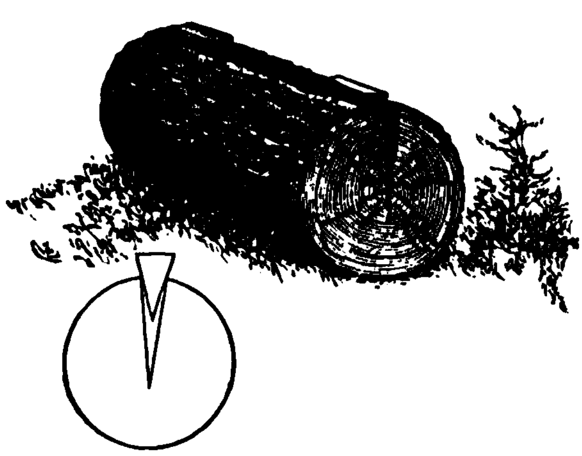


FIG. 62.—THE WEDGE.

the principle of the wedge. The surfaces of the wedge may be curved instead of plane, as in the case of the points of pins and needles, awls, etc., and the sharp edges of all cutting tools as seen through a magnifier.

The mechanical advantage gained by the wedge is greater as its slope is less; but for cutting tools the slope has to be adapted to the materials to be cut, being less for wood and soft substances than for iron and other metals.

QUESTIONS.—Describe the Wheel and Axle. Deduce its law. How is it related to the lever? Give examples. If the length of lever used in a capstan is 4 feet and the drum is of 6 inches radius, how much pull on the rope would be created by a force of 50 pounds on the end of the bar? Describe the Inclined Plane. Give examples. What is meant by the grade or slope of an inclined plane?

A plane rises 4 feet in 200 feet. What is its grade or slope? Measure the slope of *a d* (Fig. 60). If the weight W is 10 pounds, what is the pull *gi*? What is the pressure *g j*? How much weight would be required at P to prevent the cart from moving?

A horse is going up a hill with a grade of 5 feet in 100, and is drawing a load of a ton. How much force must he pull with? If he has to do 10 per cent additional work for friction, how much must he pull? If he ascends 150 feet vertically, how much work must he do, B. E. U.? If the grade is twice as great, how much must he pull?

Measure the slope of the plane *ad* in Fig. 61. How much of a load on A can a force of 100 pounds at P balance?

What is meant by the angle of repose? Give examples.

What is the Wedge? Give illustrations. How does the mechanical advantage of the wedge depend upon its slope?

SCREW.—PULLEY.—BALANCE.

The Screw is one of the most important modifications of the inclined plane. Let A B (Fig. 63) represent a solid, circular cylinder of metal or wood. Let C D E F be a sheet of paper cut so that C D is perpendicular to D E, and C F slopes by any suitable amount. The paper will then illustrate the side view of an inclined plane as in Figs. 60 and 61. Fasten this on the cylinder with C D parallel to its axis, and then wrap the paper around the cylinder. The edge C G F will wind itself up as a spiral line around the cylinder, as shown in the dotted lines G, H, I, etc.

Examine the figure A′ B′, which is the side view of a square-threaded screw; or, better still, examine an actual screw. You will see that the lines G′ K, H′ L, I′ M of the threads of the screw correspond to the lines G, H, I, etc. The upper and also the under surface of the square-threaded screw constitute a narrow inclined plane, but wrapped around a cylinder instead of being flat. If you turn such a screw with your pencil-point in the channel between the threads, the point will rise gradually, just as it would rise along an inclined plane.

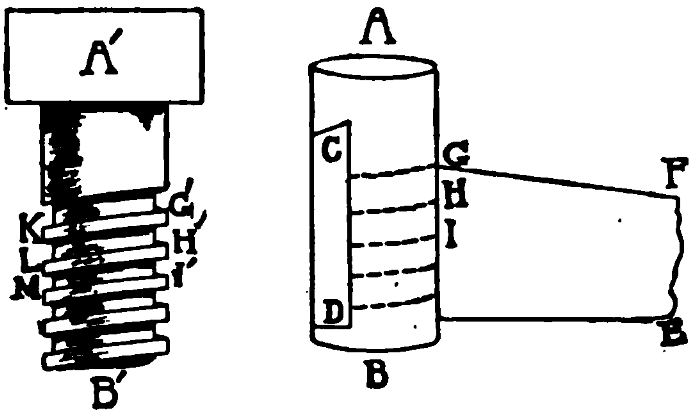


FIG. 63.—PRINCIPLE OF THE SCREW.

Most screws are made with a V-thread, as at P (Fig. 64), instead of the square one; but you will easily see that this in no way changes the principle of their action.

The Nut is a piece of metal bored out and then cut with a spiral channel in such a way as just to fit the screw (see N, Fig. 64). When a screw is driven into wood, the fibers of the wood are crushed into such a form as fit the threads of the screw just as the nut does at N.

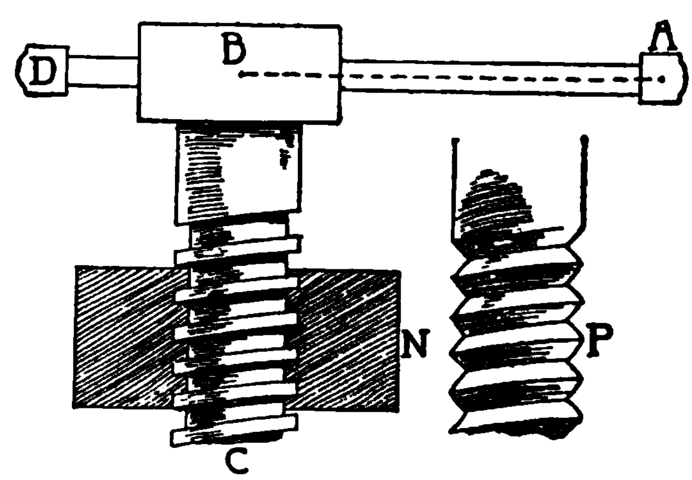


FIG. 64.—SCREW AND NUT.

One application of the screw as a machine is to produce great pressures. Suppose the nut N (Fig. 64) to be held firmly in place and the handle A of a lever in the head of the screw to be turned in such a way as to advance the screw. Any object at C would be pushed upon with a great pressure. Or the screw may be held from advancing, and the nut will then be pressed forward or backward.

The Pitch of the Screw is the distance between the successive threads, as G′ H′ or H′ I′, etc. (Fig. 63). For in-

stance, if this distance were $\frac{1}{20}$ inch, the screw would be said to have a "pitch" of $\frac{1}{20}$ of an inch; or it would be said that the screw had 20 threads to the inch. From the law of the inclined plane, it will be seen that the pitch of the screw corresponds to the height of the plane and the circumference to the base. The law of the screw could then be deduced from that of the inclined plane, but it is better to deduce it directly.

Suppose the screw turned by energy causing a force P at A always at right angles to the lever A D. Let A B be the arm of this force; then the distance S passed over by A in one turn of the screw will be the circumference of a circle with A B as a radius (viz., $S = 2 \times 3{\cdot}141 \times AB$). The work done upon the machine will be $P \times S$. In one turn the screw will be advanced at C by a distance equal to its pitch, which we will call s. Let F represent the force exerted by C. The work done at C will then be $F \times s$. Neglecting friction, then, we must have $F \times s = P \times S$, or $F : P = S : s$; or $F = P \frac{S}{s}$.

By way of example, if we had a screw of a pitch of $\frac{1}{6}$ inch turned by a force of 50 pounds at the end of a lever of length $AB = 2$ feet, how much work could that screw perform per rotation and how much force or pressure could it produce at C? The work it could

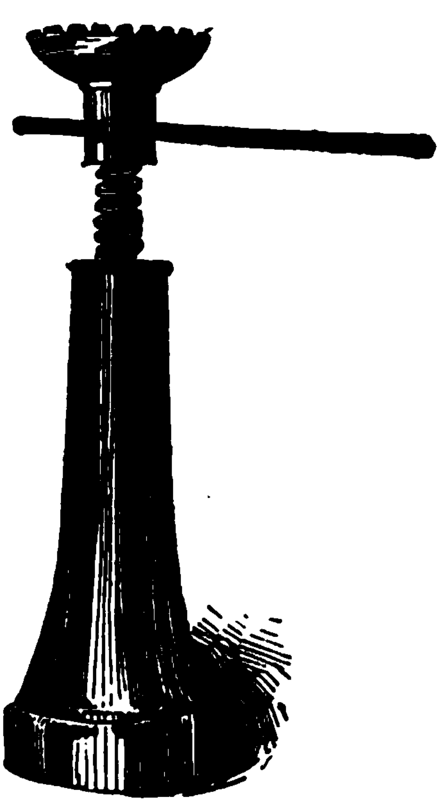


FIG. 65.—JACK-SCREW.

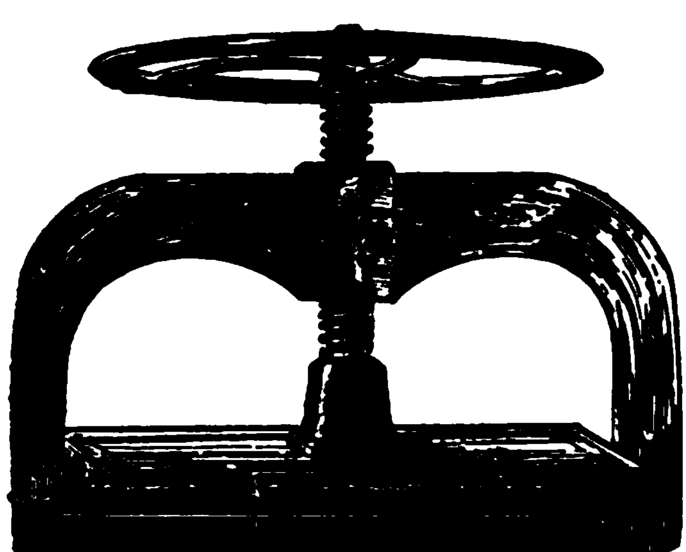


FIG. 66.—LETTER-COPYING PRESS.

do per rotation would be $F \times s = P \times S$. Now, $S = 2 \times 3{\cdot}14 \times 2 = 12{\cdot}56$ feet and $P = 50$ pounds, ∴ work $= 50 \times 12{\cdot}56 = 628$ foot-pounds. The force or pressure F which it could produce would be $F = P \frac{S}{s}$.

Now s must be expressed in feet if S is. Then $s = \frac{1}{5}$ inch $= \frac{1}{5} \times \frac{1}{12}$ $= \frac{1}{60}$ feet $\therefore F = \frac{628}{\frac{1}{60}} = 628 \times 60 = 37{,}680$ pounds $= 18{\cdot}84$ tons.

A screw of about these dimensions, called a Jack-Screw (Fig. 65), is used in raising buildings temporarily from their foundations, as well as for other purposes where great force is necessary. The common letter-copying press (Fig. 66) is another example of the application of the screw.

Endless Screw.—Besides its application in machines for producing great pressures and lifting heavy masses, the screw is used in various ways for transmitting motion. The endless screw (Fig. 67) illustrates this. When it rotates, its threads turn the toothed wheel. A rapid speed of the shaft of the screw is changed into a slow motion of the wheel.

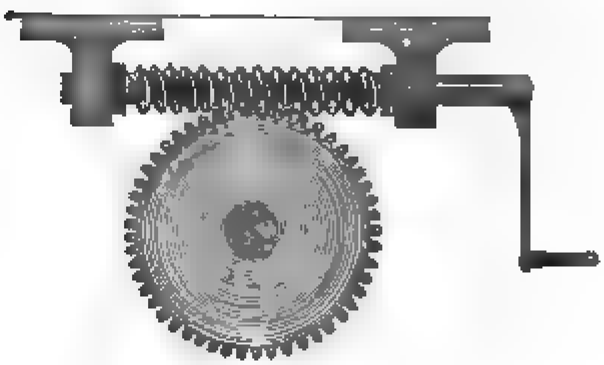


FIG. 67 THE ENDLESS SCREW.

The Pulley is merely a wheel, usually grooved on its face to hold a cord or rope, and suitably mounted on an axle. It serves merely to *change the direction* of the pull of the rope passing over it. For instance, the pulley P (Fig. 68) changes the direction of the pull A exerted by the hand to the desired direction, B. If friction be neglected, the force B equals the force A. The relative and absolute directions of the parts A and B of the rope make no difference whatever. Take the familiar case of two bodies of weights W_1 and W_2 hanging on a cord laid over a pulley (P, Fig. 12): you know that, except for friction and weight of cord, W_1 must

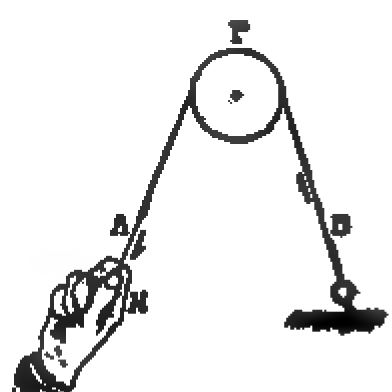


FIG. 68.—THE PULLEY.

equal W_2 in order to balance. This is only a special case of the pulley where the forces happen to be vertical.

If you pull steadily upon the end of any rope or cord in any position, there must be at every point throughout the cord a pull of the same amount, except for slight differences due to the weight of the cord itself or to friction.

A mechanical advantage may be gained by combining two or more pulleys. In Fig. 69, A is a fixed and B a free pulley. The rope is fastened to the bottom of the block A, thence goes under B, then over A, and then passes to any point P at which the power is applied. The load L to be lifted is hung upon B. Note that there are two lines of rope connecting A and B. If, now, P is pulled sufficiently to lift L, you will see that for every foot that B (and therefore L) is raised, each line of rope between A and B must be shortened one foot, and therefore two feet of rope must be taken over A toward P. That is, for each foot that L is lifted, P must move back through two feet.

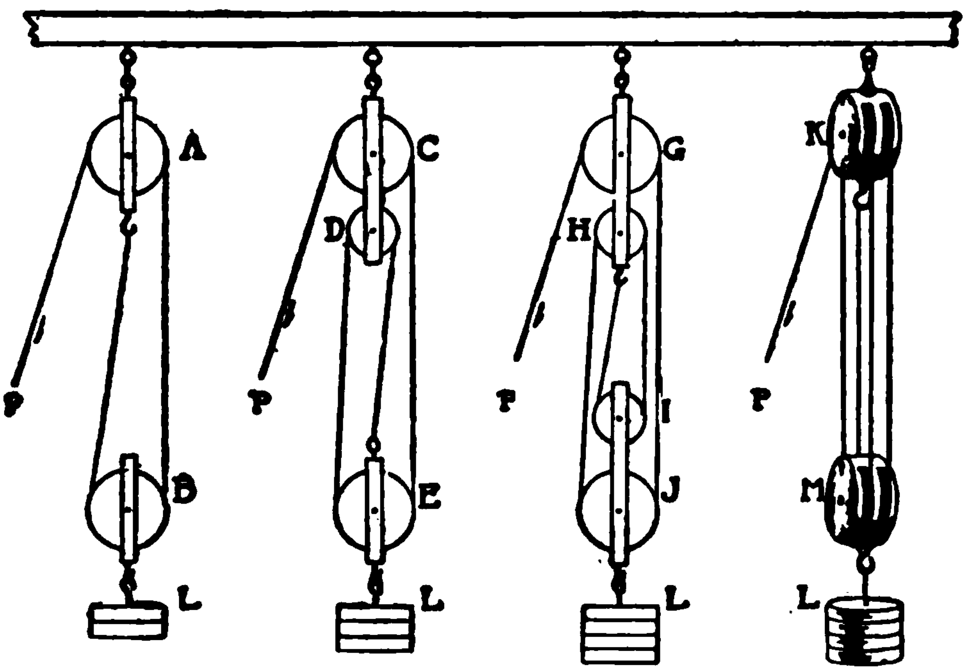


FIG. 69.—COMBINATIONS OF FIXED AND FREE PULLEYS.

In the second set of pulleys, the pulleys C and D are fixed and E is free. There are three lines of rope connecting the fixed and free pulleys. Then for each foot that L rises, three feet of rope must be pulled back toward P. In the third set, there are four lines of rope between the fixed and free pulleys. Hence P moves back four feet for each foot of rise of L.

Law of the Pulley.—In every case, then, the law of the pulley is as follows: Let S represent the distance through which the moving force P is exerted, and s that through which the load L is raised. The work done by P will be P S, and this must be equal, neglecting friction, to the work L s done upon the load. Then $PS = Ls$, or $P : L = s : S$, or $L = P\frac{S}{s}$.

In all cases $S : s = n : 1$, where n is the number of lines connecting the fixed and movable pulleys.

EXAMPLE.—If we wish to raise a load L of 1,000 pounds by the third set of pulleys, how much would be the least pull required at P? In this set $n = 4$ ∴ $P : 1{,}000 = 1 : 4$, therefore $P = \frac{1000}{4} = 250$ pounds.

Note that in this as in other machines the working force must be greater by an amount necessary to do the work of friction and of acceleration. The amount of friction in the pulleys is so great that a very large part of the work is wasted, and there is no practical gain in using a pulley of more than two or three sheaves. The mechanical advantage gained is an increase of force.

For the sake of compactness, where there are several pulleys at each end they are put side by side in a "block," as shown in the fourth set in Fig. 69. The single wheels in such a block are called the "sheaves." The whole system is sometimes called a "tackle."

The Knee or Toggle Joint.—Two bars jointed at A and pressing at B and C against any two desired objects,

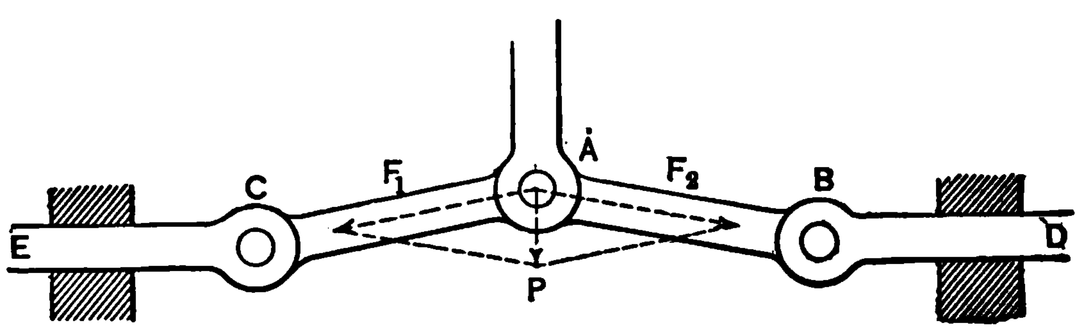


FIG. 70.—THE KNEE OR TOGGLE JOINT.

form this machine. The bars A C and A B are almost in line, so that the angle B A C is nearly 180 degrees. If a force is applied at the joint, as shown in amount and direction by P, it will produce large forces F_1 and F_2 tending to push the surfaces at B and C apart. It will be seen that the

nearer in line A B and A C come, the greater the forces F_1 and F_2 produced by a given working force P.

The Equal-Arm Balance is an adaptation of the lever for the purpose of weighing. It consists of the "beam" A B (Fig. 71), supported on the knife-edge C, usually a three-cornered steel bar passing horizontally through the beam at right angles to it. The sharp lower edge of C rests on steel or agate supporting plates, D. At the ends F and G of the beam are two smaller knife-edges parallel to the other, but edge upward. These edges are at equal distances

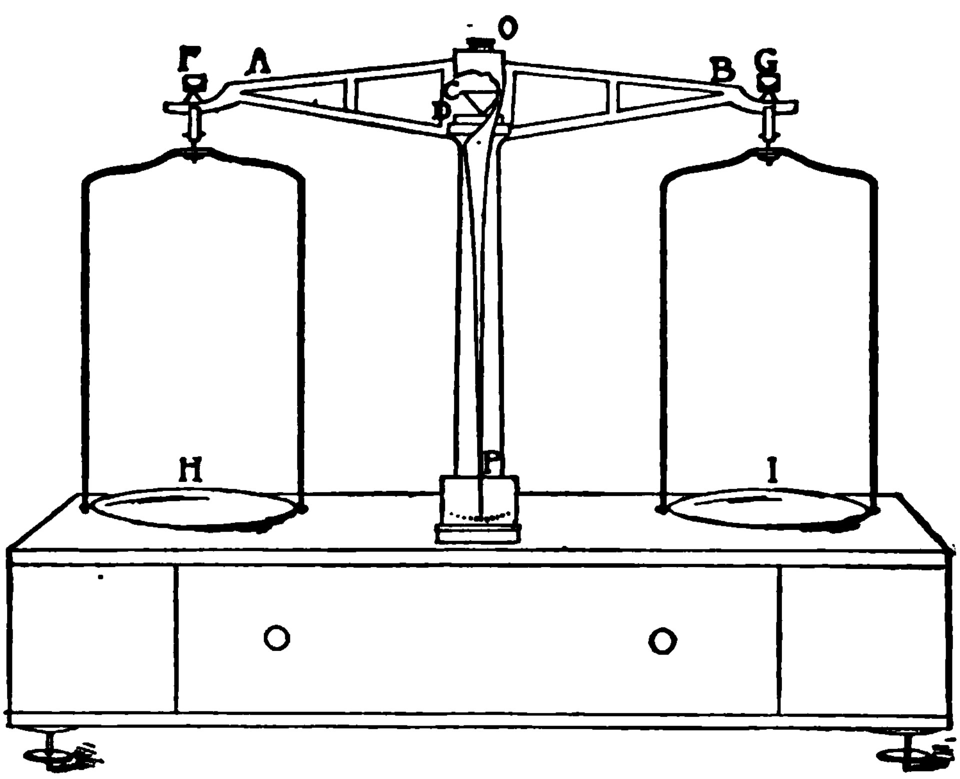


FIG. 71.—THE EQUAL-ARM BALANCE.

from the central knife-edge, and on this the accuracy of the balance depends. Hung upon these end knife-edges by means of steel or agate plates are the scale-pans H and I. In one pan is placed the object to be "weighed," and in the other are placed the standard masses. A pointer P is attached to the beam at O, and as the beam tips, this moves over a graduated scale.

The equal-arm balance has been carried to a very high grade of accuracy. It has been made so sensitive as to detect a difference of much less than one millionth part of the whole mass upon it, and to show the weight of less than $\frac{1}{100}$ milligramme. The balance used in

ordinary chemical analysis will weigh to about 1 part in 100,000, and will measure 0·1 milligramme in masses of a few grammes.

Weighing.—The use of the balance is called Weighing. It is a process for ascertaining the mass of any body, and depends on the principle of the equilibrium of moments. The arm of one force is C F, that of the other C G, and these are made exactly equal, as are also the weights of the pans. The balance can swing evenly only when equal forces are applied at F and G—that is, when the weights of the substances in the pans are equal.

The process is as follows: The balance is set swinging without a load, to see if it is in "adjustment"—i. e., if it swings equally on each side of the middle point; if not, it is adjusted until it does so. The body whose mass is to be determined is then put into one pan, usually the left-hand one for convenience. Masses from the graded set of masses (pages 81 and 89) are put into the other pan until the pointer again swings equally. The weight of the unknown body and of the known masses in the pan are thus shown to be equal; therefore, the masses are also equal. The mass of the unknown body is found by adding the known masses used.

If the balance arms C F and C G are not exactly equal, then there will be an error in the result. This may be avoided by putting the object in the right-hand pan, and filling shot or sand into the left until equilibrium is obtained; then removing the object and putting in standard masses until equilibrium is again obtained. A rough balance may thus be made to give much better results.

QUESTIONS.—Show how the Screw is a modification of the inclined plane. Describe the Nut. Define the pitch of a screw. How may the screw be used to obtain great pressure? State the law of the screw as thus used.

A jack-screw, with a pitch of one quarter of an inch, is turned with a force of 75 pounds at the end of a lever of 2 feet; how much pressure could the screw produce, neglecting friction? How much work can it do per turn?

Describe the Endless Screw. What is a Pulley? What is its use? How can a mechanical advantage be gained by the use of a combination of pulleys? State the law of the pulley. Show how this is true from the amount of rope drawn through each of the pulleys. State the rule for finding the ratio of motion of power to load. In each of the four sets of pulleys of Fig. 69, what load would a power of 100 pounds just balance? Describe the Knee or Toggle Joint. In Fig. 70, suppose that $P = 100$ pounds, what would be the amount of F_1? What would be the force with which D and E would be pressed upon? Describe the balance; the process of weighing.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Suggest a reason why rollers are used in moving heavy blocks of granite.

When brakes are applied to the wheels of a heavily-loaded stage-coach in descending a hill, what is accomplished, and why?

Why is it more difficult for a pair of horses to start a street-car than to keep it in motion after it is started?

Explain the reason why you can go so fast on skates. Why sleighs are used in winter instead of wagons.

Do you find it easier to walk on a carpeted floor than one of polished hard wood? Think of a reason.

Could a carriage progress without friction? Can a train be moved if the rails are thoroughly lubricated? *Grasshoppers crushed by the wheels of the cars have been the means of stopping trains in the West.*

Analyze the action of a tack-hammer in drawing a nail. Where is the fulcrum? The weight? The power?

Of what order of lever is the common chopping-knife? A pair of tongs? A nut-cracker? A piano-pedal?

The farther from the rowlocks you grasp the oars, the more easily you propel your boat. Why? What do we here mean by "more easily"?

Did you ever attempt to lift a ladder from the ground by walking under it and grasping round after round in succession? Why did you experience difficulty, or were perhaps forced to give up the feat, as you approached the bottom?

Account for the difficulty of holding out a heavy weight at arm's length.

A machine takes up 4 foot-pounds of energy for every 2 foot-pounds it gives out; what is its efficiency?

A dynamo-electric machine, having an efficiency of 93 per cent, receives 2,000 foot-pounds of energy; how much electrical energy does it give out? It receives energy at the rate of 40 horse-power; at what rate does it give out electrical energy?

With a pair of tongs 3 feet long a pressure of 5 pounds is desired between the points; the hands are held one foot from the hinge; how much force must be exerted?

In Fig. 54 find the leverage by measurement. If the barrel weighs 150 pounds, how much pressure must be exerted? What gain of work is made?

Does a horse drawing a carriage up-hill where there is a rise of 1 in 20 really lift one twentieth of the load? Explain why.

Why does the driver of a heavy load in ascending a hill take a zigzag course?

A farmer, in forcing a stump from the ground, uses a crow-bar 6 feet long, which he rests on a stone 5 feet from the end where his hand is applied. The resistance of the stump is equal to a weight of 500 pounds; how great a pressure must he exert to move it?

A man weighing 180 pounds and a boy of 60 pounds are teetering on a board 12 feet long. That they may balance each other, how near must the man sit to the horse on which the board rests?

Four men are drawing in, with a capstan, an anchor that weighs 1,000 pounds. The barrel of the capstan has a radius of 6 inches. The circle described by the handspikes has a radius of 5 feet. How great a pressure must each of the four men exert to move the anchor?

With a fixed pulley, how great a power will it take to hoist a weight of 50 pounds, 20 per cent, or one fifth, being added for friction?

A book-binder has a press, with a screw whose threads are one third of an inch apart, and a nut worked by a lever which describes a circle of 8 feet; how great a pressure will a power of 5 pounds applied at the end of the lever produce, the loss by friction being equivalent to 240 pounds?

THE THREE STATES OF MATTER.—SOLIDS.

DIFFERENCES IN THE THREE STATES OF MATTER.

Matter exists in Three Conditions or states, which are called respectively the Solid, the Liquid, and the Gaseous State. Liquids and gases are also called Fluids.

Solids.—You are familiar with matter in what is called the solid state. A stone, a piece of wood, metal, or ice, are every-day examples of solids. If you think about all the solid substances which you can call to mind, you will see that they have this property in common, viz.: *They retain their shape when left to themselves, and can only be made to change shape by the application of energy.*

Liquids, on the other hand (water and mercury are every-day types), must be held in a vessel of some kind. If left to themselves they do not retain their form, but spread out over the surface on which they are placed. Owing to the action of their weight, liquids do not require to be held down at their upper surface, but can be kept (except for evaporation) in a vessel open at the top. All liquids may probably be reduced to solids by sufficiently great cooling. Nearly all have been thus solidified.

Gases, like liquids, require to be held in a retaining vessel; but, unlike liquids, if left to themselves, gases will spread or expand in *all* directions. Hence the vessel containing them must be closed on all sides. Air is a common

example of a gas, or rather of a mixture of gases. All gases may be reduced to liquids: some by great compression alone; others by great cooling alone; others require both cooling and compression combined.

The Molecular Differences in the Three States are as follows: In all three states the molecules are in the continual to-and-fro motion of heat-energy, but with this difference—in the solid state, the molecule does not wander about through the body, but remains always at or very near the same point, simply moving to and fro, somewhat as a pendulum-bob vibrates about its point of rest, but more irregularly. In the liquid state, every molecule does wander in a very irregular path, and somewhat slowly, through the body of the liquid, being now at one point and presently at another, jostling violently around among its neighbors. In gases, each molecule moves around as in liquids, but much faster and with a freer motion. The spaces between the molecules are much greater, so that they can move farther without jostling against one another.

We have now to consider some of the properties and laws of matter in these three states.

PROPERTIES OF SOLIDS.

Cohesion. — Adhesion. — Take hold of the ends of your pencil with your fingers, and pull lengthwise (not crosswise), as if trying to pull it apart. It resists so strongly that you can not do so. Try to break any object in any way; the breaking is more or less resisted. Break a small stick of wood by pulling or bending. It breaks by the pulling apart of its molecules. Put the broken surfaces again together, and they do not hold. Yet the only difference in conditions is that you are unable to get them back to the same closeness of contact that they had before.

There appears, then, to be some form of energy which causes an attractive force between molecules of the same

kind, this force being very great at extremely short distances, but being so slight as to be imperceptible at distances of a few thousandths of an inch. The property of possessing this force is called Cohesion, and the force is called the Force of Cohesion, or often merely Cohesion.

A similar force exists between surfaces of matter of different kinds. It is shown when you try to pull apart pieces of wood glued together, or cemented bricks. The force which holds the glue to the wood or the cement to the brick is an attraction between materials of different kinds, and is called Adhesion. The distinction between cohesion and adhesion is of little consequence; they are probably both due to the same form of energy.

Cohesion and adhesion exist in liquids, and probably in gases to a very limited extent.

It is to cohesion that the strength or tenacity of materials is due, and the limit of strength is reached when the force applied to the body is equal to the cohesive force exerted by the body in opposition to that force. That surfaces may be brought so closely into contact as to cohere or adhere, is shown by the fact that gluing, cementing, soldering, welding, varnishing, etc., are possible.

Experiment.—Cut a lead bullet in two, and make the fresh surfaces exceedingly smooth and flat. Press them firmly together. They will cohere perceptibly. Lay a very smooth piece of plate-glass on the table. Place upon it another (of a little larger size, for convenience of lifting by the edges), and put a weight upon them. After a while carefully remove the weight, and pick up the top plate. The lower plate will be found to cohere more or less strongly. Two such plates left lying together for months or years may cohere so strongly as to be more easily broken than pulled apart. Machinists and others who have occasion to make very truly plane surfaces have what they call "surface plates," by which to test the surfaces which they are making. These consist usually of three steel plates which have been alternately ground together in pairs until each fits both the others, and all are therefore plane. If these be cleaned and put together, they adhere quite firmly, even *in vacuo.*

Welding is a process of making metals cohere or adhere. The surfaces to be joined are cleaned and made of

suitable shape. They are then heated, and while hot are cleaned again by means of a material called a flux (rosin, borax, etc.), and brought into contact. They are then hammered or pressed together to bring them into closer contact, and allowed to cool. When cold, they cohere or adhere nearly or quite as strongly as the other parts of the material. The blacksmith can thus weld wrought-iron easily and a few other metals with difficulty; but the process of welding by electricity has rendered this property available in the case of almost all metals.

Hardness.—A body is said to be harder than another when it is capable of scratching the former but not of being scratched by it. The diamond is the hardest of all solids. Hardness is made use of in mineralogy as a means of identifying minerals. By sudden cooling from a high temperature, steel and some other bodies acquire great hardness, usually accompanied with increased brittleness. Bodies thus treated are said to be *tempered.*

Ductility is that property which renders some materials capable of being *drawn out* into wires or threads. Glass when hot can be spun into threads. Warm wax can also be thus treated. Many metals when cold possess the same property. Thus, gold, silver, platinum, iron, copper, palladium, aluminum, zinc, tin, lead, can all be drawn into wires when cold by pulling them through hard metal plates bored with holes of suitable sizes. Gold is the most ductile metal, and the others stand in the list above in the order of their ductility.

Malleability is that property which renders a body capable of being hammered or rolled into sheets. Gold, copper, and other metals are quite malleable. This property and ductility are closely related; but the metals do not stand in precisely the same relative order for the two. Consult pages 62 and 67.

Elasticity.—From the experiments described on pages 49 to 52, you have learned that when a force is applied to a body which is prevented from being accelerated, the body is changed in size or form; also, that when the applied force is removed, the body will more or less completely regain its original form. The force acting in such a case is called the *Stress*; the change in form produced during its action is the *Strain.* Elasticity is that property by virtue of which a body (whether solid, liquid, or gaseous) requires force to change its bulk or shape, and resumes its form when the force is removed.

Suppose you were to take a round rod of rubber a foot long and an inch in diameter and a piece of steel of the same size, and were by any means to hold each stretched by the one-thousandth part of its length. To do so would obviously require a much greater force with the steel than with the rubber. Which is the more elastic? You would perhaps naturally say the rubber; but this is not the case. The rubber is the more *extensible*, but the steel is the more highly *elastic.* The elasticity of a body is measured by the amount of force required to produce a specified change of size or form; hence the greater the force required, the greater the elasticity.

When we are dealing with the reduction of the volume or length of a body by pressure, we speak of compression; when with the increase of length, of extension; when with its bending, of flexibility. The latter is, as stated on page 51, a combination of compression and extension. If we say that one body is twice as compressible or extensible or flexible as another, we mean that equal forces will produce twice the amount of compression or extension or bending on pieces of the same size. In such a case, the first body would be only half as elastic as the second.

Some substances can be stretched, compressed, or bent but a little before breaking, and are said to be *brittle.* Substances the reverse of these are called *tough.*

Most substances when strained do not entirely recover their original forms. They are therefore said to be *imper-*

fectly elastic, while those which do recover completely are called *perfectly* elastic. Many substances appear to be perfectly elastic if not strained beyond a certain amount.

Hold in the hand or under a clamp one end of a bit of iron or copper wire. Pull the other end aside a very little so as to produce slight bending, and let it go. After vibrating for a while it will settle down in its original position of rest. So far as you can see, it is perfectly elastic. Repeat the experiment, bending the wire a little more each time. You will soon find that the recovery is not perfect, but that the wire has been "bent," or has taken what is called a "permanent set." Its elasticity is perfect only below a certain amount of strain.

This amount or limit below which the substance is perfectly elastic, or sensibly so, is called the *limit of elasticity*. Some solids (steel, glass, etc.) can be strained nearly to the breaking point without passing this limit; others (wax, rubber, copper, gold, and ductile materials generally) reach the limit at much less strain than is required to break them. If a substance is kept in a strained condition for a long time, it will generally show a permanent set on being released, even when it has been strained much less than up to what appears to be its limit of elasticity for strains of short duration.

Structure.—Examine and compare a lump of blue vitriol (copper sulphate), a piece of mica, a bit of pine wood, a piece of sandstone, a fragment of glass. You will find the lump of vitriol made up of a number of more or less regularly shaped masses of the salt. It is composed of imperfect crystals, and is said to have a *crystalline* structure. Most crystals split or "cleave" more readily in some directions than in others. Thus mica splits into thin plates or layers (*lam'inæ*), and is therefore said to have a *laminated* structure. Wood splits easily along the grain or fiber, and is said to have a *fibrous* structure. Sandstone is made up of a multitude of grains, and is therefore described as having a *granular* structure. Glass splits equally well in all directions, and appears to be without structure, which is expressed by saying that it has an *amorphous* (*without form*) structure.

EXPERIMENT.—Dissolve a small handful of alum in about twice its weight of hot water. Hang a thread down into the middle of the

liquid and stand it aside in a quiet place free from dust. In a few hours or days there will be found on the thread crystals of alum more or less perfect. Similar experiments may be made with copper sulphate, common salt, and other substances.

If in the winter you catch snow-flakes on a dark cloth, you will see, especially well with a magnifier, that they are usually composed of regular and beautiful crystals of ice (see page 277). The frost which forms on the window-pane is also generally crystalline.

Viscosity.—Certain substances which we commonly regard as solids do not strictly fulfill the definition of a solid as a substance which holds its form when left to itself.

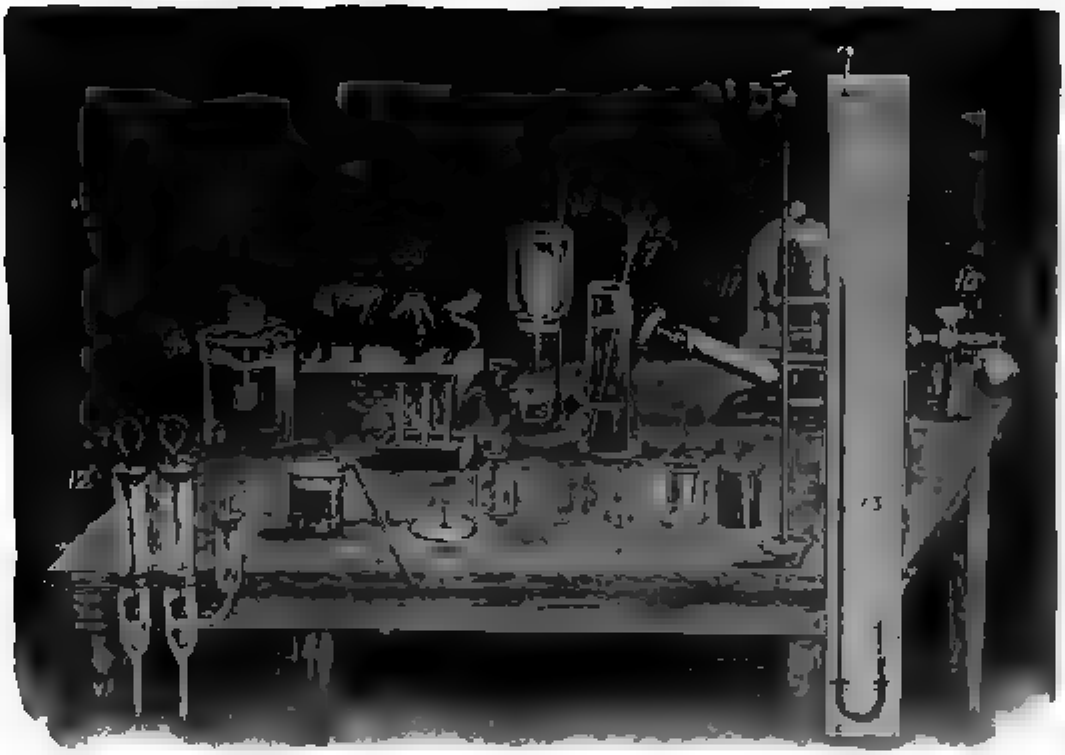
Experiment.—Fasten one end of a stick of sealing-wax so that it projects horizontally, as the stick in Fig. 14. Leave it for a day or two. The projecting end will have become permanently bent downward. A piece of pitch left lying upon a table will after several days be found to have flowed out into a flat mass, as thick molasses would have done much more quickly.

This slow change of form is due to a sort of flowing of the parts of the substance. Solids acting in this way under ordinary conditions may properly be considered as imperfectly solid. They are said to be *viscous*.

Questions.—What are the three states of matter? What is the characteristic by which we recognize Solids? Give examples of solids. Is putty a solid? Is ice a solid? What is the main distinction between solids and liquids? Give examples of liquids. Are sealing-wax and pitch liquids? How may liquids be rendered solid? What is the chief distinction between gases and liquids? Give examples of gases. How may gases be reduced to the liquid condition? Give an example of some substance which you know of as capable of existing in all three states. State the molecular differences between the three states.

Show that Cohesion and Adhesion exist in solids. What is the distinction between the two terms? Do these properties exist in liquids and gases? To what extent? Is cohesion or adhesion perceptible at long distances? Give examples to show what the distance is at which they are perceptible. To what is the strength or tenacity of materials due? To what form of energy is cohesion due? On what does the possibility of welding, soldering, gluing, etc., depend? Describe these processes. Describe an experiment showing the adhesion of liquids to solids. One showing the cohesion of liquids. What is meant by Hardness? By Temper? By Ductility? Give examples.

Define Malleability, Elasticity, Stress, Strain. Which is the more elastic, iron or wood? Brass or rubber? Which is more easily extensible? What is meant by Brittleness? By Toughness? Illustrate. Give examples of permanent set. What is meant by limit of elasticity? Describe crystalline, laminated, fibrous, granular, and amorphous structure. Define Viscosity; give an example.



LIQUIDS AND GASES.

PROPERTIES OF LIQUIDS.

Cohesion.—Adhesion.—If you dip a pencil or your finger into water, you will find, on drawing it out, that some water clings to it. This is because the water *adheres* to the pencil or finger, and also *coheres*—that is, holds together. Most other liquids act similarly; but mercury and certain molten materials do not, although they possess the properties of cohesion and adhesion.

NOTE.—The properties of liquids and gases discussed in the following sections may be illustrated measurably with the apparatus shown above. Methods of constructing simply and cheaply various essential pieces are suggested in the text. No. 1 represents an adhesion plate; 2, cohesion figures; 3, equilibrium tubes; 4, upward pressure apparatus; 5, brass bucket with accurately fitting solid piece of brass to illustrate the principle of Archimedes; 6, capillary tubes; 7, tall glass jar, with tube and funnel; 8, stoppered glass bottle; 9, barometer tube; 10, hollow copper globe for weighing air, with stop-cock and scale-beam for suspension; 11, automatic table air-pump; 12, lifting and force pump; 13, Boyle's law apparatus; 14, siphon, 15 large-mouth glass bottle, inverted over porous cup, from which a glass tube dips into a tumbler of water. The iron stand is similar to that described on page 230. Teachers and pupils are referred, for such of this outfit as they can not readily construct for themselves, to any instrument-maker.

EXPERIMENTS.—At the middle of a thin disk of metal or glass, fasten a hook with solder or wax, as shown in Fig. 73, or drive a screw-eye into a flat piece of wood. Into the hook or eye, loop a rubber band. Bend the hook until the disk hangs truly horizontal. Then, holding the upper end of the rubber in the hand, lower the disk (which must not be greasy) until it touches a water surface. Pull carefully straight upward. You will find that you have to pull quite hard, as you perceive from the stretch of the band, before the disk tears away from the water. The water and disk therefore adhere. But this experiment also illustrates the cohesion of the water; for, if the particles of water did not hold together, the disk would have to lift merely the weight of those particles which adhered to it, and would therefore be no harder to lift before it separated from the liquid than afterward. In fact, what we really do when we pull the disk away from the liquid, is to tear apart the cohering water particles, and not to pull apart the water and the disk.

FIG. 73.—ILLUSTRATING THE ADHESION AND COHESION OF WATER.

Dissolve in warm water about one fortieth of its weight of pure soap. Filter through thin filter-paper. Add about one half the bulk of glycerine, and let the mixture stand for several days. Cool by placing on ice, and then filter a second time. Next procure several feet of No. 18 or 20 annealed iron wire, and make up, of a size of an inch or more to a side, some of the forms shown in Fig. 74. Dip the circle into the soap solution. On drawing it out, a thin film will be found filling the circle. This illustrates both adhesion and cohesion. How? Dip the other forms. They will show when taken out extremely interesting combinations of films. By breaking one or another of the several films of the cube, peculiar curved surfaces can be formed.

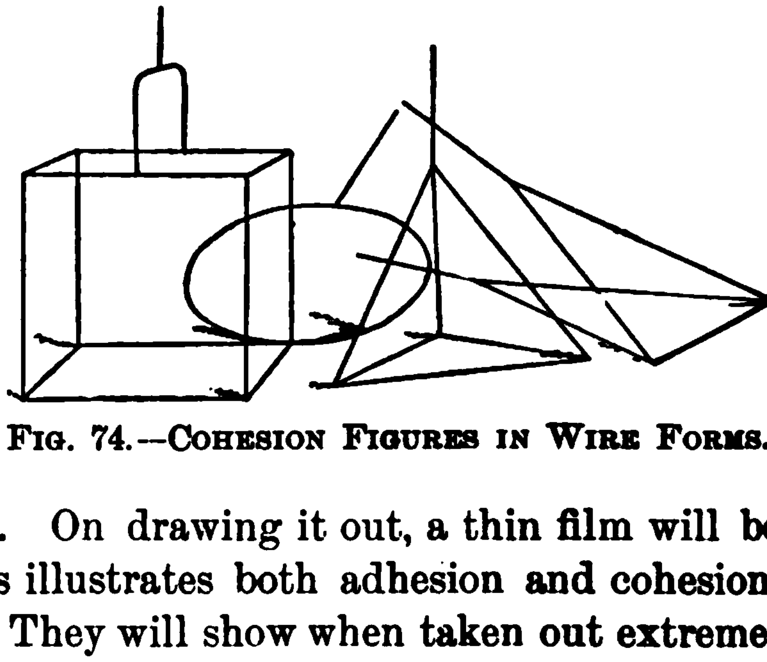


FIG. 74.—COHESION FIGURES IN WIRE FORMS.

The tints of these films are often very beautiful. Large bubbles may be blown with this solution, and they will illustrate many phenomena of cohesion, color, etc.

Surface Tension.—Let water drop slowly from the end of your finger. A drop as it falls through the air is spherical. Rain-drops are also spherical, as you can see by watching closely, and as is proved by the rainbow (see page 368). A drop of water on an oily or smoked surface, or a drop of mercury on the table-top, has the form of a sphere. Why is it that these small masses of liquid take this form?

Remember that the force of cohesion between the molecules is very strong when they are exceedingly close together, but ceases to be sensible at even very short distances. Let *a*, Fig. 75, represent a molecule inside a mass of liquid. Then *a* would feel the pull of all the molecules which are within a certain short distance of it, but not of those beyond that limit. Let the small dotted circle indicate a sphere described about *a* as a center, at such a distance that the attraction on *a* of all molecules inside the sphere is sensible, but that of those outside is insensible—i. e., is less than some specified small amount. This sphere is called the *sphere of attraction* of *a*. For water, the radius of this sphere—i. e., the distance at which cohesion ceases to be sensible—is about two millionths of an inch. Now there would be the same number of molecules on all sides of *a* within its sphere of attraction; hence *a* would be equally pulled in all directions, and cohesion would not, therefore, tend to move it in any one direction more than another.

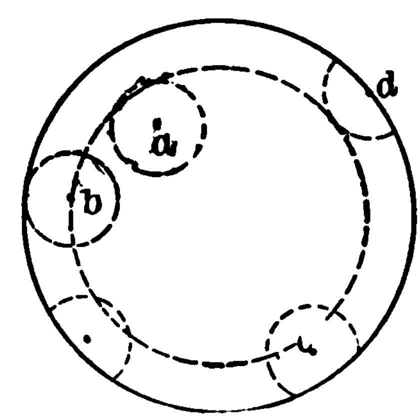


FIG. 75.—SPHERE OF ATTRACTION.

Suppose now that we have a drop of water represented as highly magnified by the outside circle of Fig. 75. Let the large dotted circle be drawn so that its distance from the outer one is just equal to the radius of the sphere of attraction (two millionths of an inch). Any molecule lying inside this dotted circle will then be equally pulled in

all directions. But for all molecules, for instance, *c* and *d*, lying between this and the surface of the drop, there will be no molecules in those parts of their spheres of attraction which are outside the drop surface. Hence all molecules near the surface will be more strongly attracted toward the interior of the drop than toward its surface, and for those molecules very close to and at the surface, the pull will be very strong. This is true of every free liquid surface (i. e., not bounded by a solid or other liquid). Thus the surface molecules are under a strong inward pull, and form a sort of skin over the drop, which acts like a stretched elastic bag, as in a toy balloon. The surface of a liquid, therefore, acts as if it were under a continuous pull or tension; it is therefore said to have a Surface Tension. By this surface tension the liquid is forced to take that shape which gives the least surface for the given volume of liquid, and that shape is a sphere.

A perfectly spherical form is not attained by a drop lying on a solid surface, because the weight is great as compared with the cohesive force, and flattens the drop out. The rounded form of a drop of melted wax, of the softened end of a melted stick of sealing-wax or of a glass tube or rod, of a soap-bubble, etc., is due to the action of the surface tension, as are also the phenomena of capillarity about to be described. Solid surfaces also must possess a surface tension, but its effects are seldom perceptible.

Annealing.—A similar condition of surface tension is exhibited by "Prince Rupert drops," which are made by allowing drops of molten glass to fall into water. The outer surface of a drop is thus suddenly hardened, while the interior remains liquid. As the interior gradually solidifies, it contracts, putting the surface layers of solidified glass under great stress. If the surface is scratched or cut, the crack thus started is violently spread by this stress in many directions, and the drop flies instantly into fragments. This strained condition, due to sudden cooling, may be reduced or avoided by the process of Annealing—i. e., by slow cooling either at the time of making or after subsequent heating. Most glassware has to be annealed. To produce homogeneous and unstrained or evenly strained glass for large telescope lenses, extraordinary pains are taken in the annealing process.

Capillarity.—If you dip a clean glass plate into a dish of water, the water will rise up at the surface of the plate in the curves C and D (Fig. 76) instead of lying flat. This is because the adhesion of the water to the glass much exceeds the cohesion of the liquid.

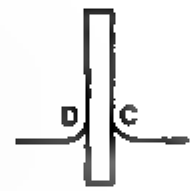


FIG. 76.

EXPERIMENTS.—Hold two glass plates with their edges together at A, but kept a very little apart at B by a bit of wire or string (Fig. 77). Dip the lower edge of the combination into water, and the liquid will rise in the form of the curve shown in the figure.

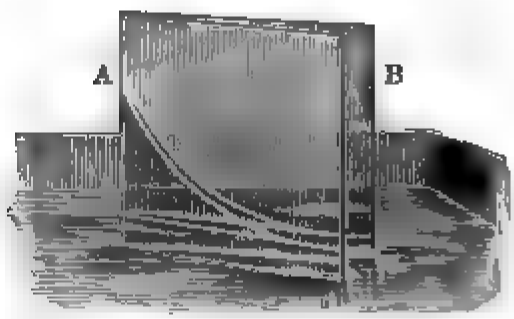


FIG. 77.—CAPILLARITY ILLUSTRATED BY GLASS PLATES.

Obtain a clean glass tube of about a tenth of an inch in diameter. Dip it vertically into water. The water will rise in the tube. Try finer tubes. The finer the tube, the higher the water will rise.

Fine tubes are called capillary tubes (from the Latin *capillus*, a hair), because of their hair-like bore. From the fact that the action just illustrated is easily seen in these capillary tubes, the phenomenon is called Capillarity.

In a glass tube one tenth of an inch in inside diameter, water will rise to a height of a little more than one quarter of an inch. ***The height for the same liquid is inversely as the diameter of the tube, but varies with the liquid.*** Thus in a tube of 0·01 inch diameter, water will rise $0{\cdot}1 \div 0{\cdot}01 = 10$ times as high as in one 0·1 inch diameter, or $10 \times 0{\cdot}25 = 2{\cdot}5$ inches.

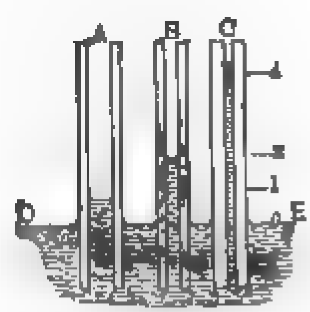


FIG. 78. WATER IN CAPILLARY TUBES.

Liquids will not overflow a tube by capillary action. If a tube 0·01 inch diameter were dipped into water until it projected only half an inch, the water would rise to the top of the tube and stop, because of the change in form of the tube at that point.

Water and most liquids adhere to glass and other solids more strongly than they cohere. But this is not true of mercury, which adheres to glass less strongly than it coheres.

EXPERIMENT.—Dip the glass plate when thoroughly dry into mercury; the curves at the contact will be downward instead of upward.

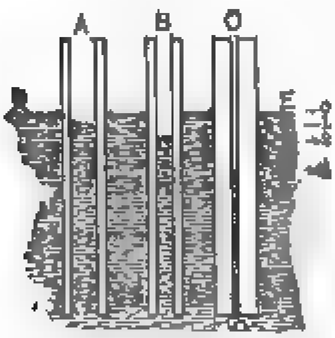


FIG. 79.—MERCURY IN CAPILLARY TUBES.

Fig. 79 shows the action of mercury if the capillary tubes of Fig. 78 were plunged into it. The cohesion of the mercury is so much greater than the adhesion to the glass that the mercury does not wet the glass like water, but assumes a convex form, as water does upon a smoked or greasy surface.

The toy called a "sucker" is a round piece of leather with a string fastened to the middle. If it be thoroughly wet and pressed firmly down upon a flat stone, some water will be squeezed out of the leather and form a film between it and the stone, forcing the air out. If the string be now carefully pulled, the stone, even if quite heavy, will be lifted. This is due to the combined action of capillarity and atmospheric pressure. The adhesion of the water to the stone and the cohesion of the water enable the concave surface, C, of the film to sustain a part of the atmospheric pressure. Thus the intensity of the pressure within the water and tending to separate the sucker from the stone is less than the intensity of the external atmospheric pressure on the upper side of the sucker, tending to hold sucker and stone together. Therefore, if the water-film be thin enough at C, and the sucker large enough, there may be a resultant pressure sufficient to equal or exceed the weight of the stone, so that it can be lifted.

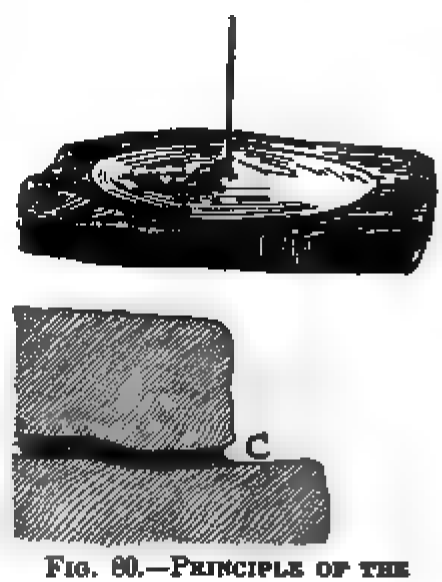


FIG. 80.—PRINCIPLE OF THE SUCKER.

Porous Objects absorb Liquids by Capillary Action.—Pores form irregular spaces, into which liquids rise or flow just as water rises in capillary tubes. Blotting-paper, a lump of sugar, a lamp-wick, absorb liquids in this way.

But you will remember that the cause of this action lies wholly at the surface of the liquid, and that as a rule the liquid can not be made to overflow. Therefore, a continuous flow of liquid can not be due to capillarity unless the liquid is evaporated or otherwise removed from the surface, as, for instance, in the case of a lamp-wick.

Compressibility.—By very exact experiments, it has been shown that liquids are compressible—i. e., that their volumes may be reduced when under pressure. Water is only very slightly compressible, even with enormous pressure.

Diffusion.—Pour into a tall glass jar or bottle enough water to fill it two thirds full. Through a funnel and long tube reaching to the bottom, introduce carefully about one third as much of a nearly saturated solution of blue vitriol. Let the glass stand without disturbance for several days. You will see that at first the surface between the blue solution and the water is sharply defined. Soon it becomes blurred, and gradually the vitriol spreads up through the liquid until the whole becomes of a uniform tint.

FIG. 81.—DIFFUSION OF LIQUIDS.

This process is called Free Diffusion. It is due to the fact already stated (page 167) that the molecules move about from one part to another of the body of a liquid.

EXPERIMENTS.—Into a similar jar put a solution of blue litmus in place of the water, and then pour in through the funnel a small amount of sulphuric acid. In the course of two days the sulphuric acid will have become diffused throughout the liquid. This will be known from the change of color, for acids turn blue litmus red. The progress of the diffusion can thus be easily followed.

Place some blue vitriol solution in a porous cup, such as is used in some electric batteries. Stand the cup in a dish of water, but with its top out. The blue vitriol will diffuse through the cup into the water. A similar experiment may be made with the acid and litmus. This *diffusion through porous partitions* is not different in character from the free or direct diffusion, but the principle is made practical use of in many ways.

Rate of Diffusion.—Some substances diffuse rapidly, others very slowly. Most of those solids which diffuse rapidly when in solution are such as have a distinctly crystalline form, such as common salt, sulphate of magnesium, etc. This class is therefore called *crystalloids*.

Of the substances which diffuse very slowly or hardly at all, gelatine, starch, dextrine, and gums are examples. They all form, when moist, more or less gelatinous or glue-like masses, and are therefore called *colloids* (from a Greek word for glue). The reason why the colloids diffuse so much more slowly, is probably because their molecules are very large as compared with those of the crystalloids, the size being due to the fact that the molecules consist of a large number of atoms. The different rates of diffusion are utilized in separating substances from a mixed solution.

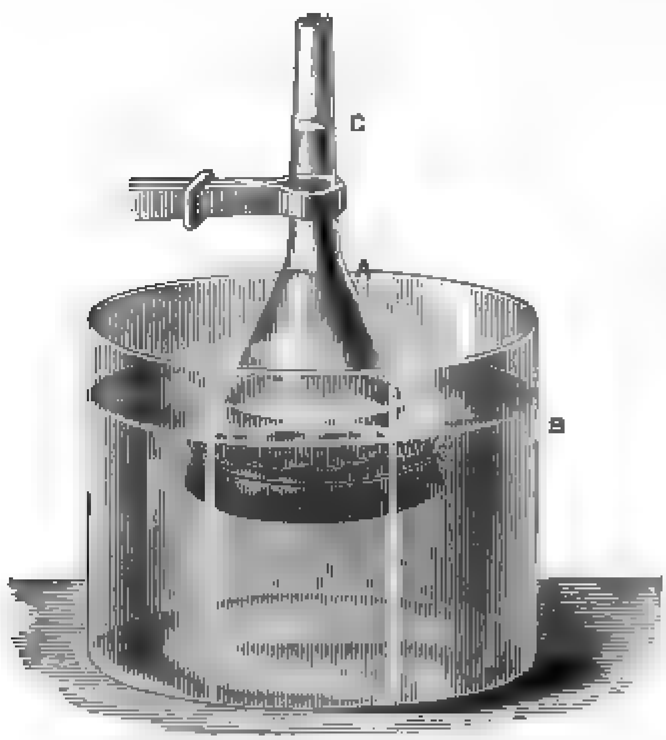


FIG. 82. DIFFUSION THROUGH ANIMAL MEMBRANE.

Osmosis.—Tie a piece of moistened bladder, frog-skin, or other animal membrane, over the end of a funnel A (Fig. 82). Fill the funnel with a strong solution of blue vitriol or sugar. Invert it in a dish of water, B,

by means of a clamp. Note the height C at which the solution stands at the outset. After an hour or two, the liquid at C will be found higher than at the start, showing that more of the liquid has diffused from B into A than from A into B; but the color (or taste) of the liquid in B will prove that some liquid has also diffused from A to B.

Thus liquids and solids in solution diffuse through animal membranes. But such membranes as the bladder are different in structure from the porous cup of the former experiment; they contain no pores which can be discovered even with a powerful microscope. Hence it is not strange that the process of diffusion through such membranes, which is called Osmo'sis, follows different laws from free diffusion or diffusion through porous substances, and depends on the nature of the membranes used. Osmosis has important practical applications. It also enters largely into the operations of Nature, causing, for instance, the ascent and descent of sap in trees and vines.

QUESTIONS.—Show that cohesion and adhesion exist in liquids. What is surface tension? To what is it due? Describe it in detail. What is meant by the sphere of attraction? At how great a distance does the cohesion of water cease to be sensible? Why do rain-drops assume a spherical form? What do the Prince Rupert drops illustrate? How are they made? What is the process of annealing?

To what phenomena is the name Capillarity given? Describe several experiments illustrating it. How high would water rise in a tube of 0·03 inch bore? Will liquids overflow in capillary tubes? Why not? Why does oil rise in a lamp-wick? If the end of a piece of dry wood is dipped into water, why does the water rise in the wood? What is necessary in order that a liquid should wet a solid? Describe the action of mercury in fine tubes. Why does it act in this way? Describe and explain the action of the toy called the "sucker."

Are liquids compressible? Describe an experiment illustrating the free diffusion of liquids. One illustrating diffusion through porous substances. What is the molecular explanation of the process of free diffusion? What is the difference between crystalloids and colloids? Describe an experiment showing the phenomenon of Osmosis. Are the laws of osmosis different from those of free diffusion and of diffusion through porous partitions? For what reason?

PRESSURE OF LIQUIDS.

Hydrostatics. — Hydraulics. — Hydrostat′ics is the name given to that branch of Physics which deals with liquids at rest; Hydraulics, to that branch which has to do with liquids in motion.

Hydrostatic Law of Transmission of Pressure.— In the case of a mass of liquid at rest, a pressure exerted at any point is transmitted equally in all directions throughout the liquid.

Fig. 83 represents a vessel filled up to *a b* with any liquid, and *a b* is a piston which can be forced down by pressure. Suppose, for example, this pressure to be equivalent to 2 pounds on each square inch of the surface of the piston. Then it will be transmitted through the liquid in every direction, so that on each square inch of the walls of the vessel, e. g., at F, E, D, C, or anywhere else, there will also be a pressure of 2 pounds to the square inch, if we neglect for the present the weight of the liquid itself. Further, if we were to put into the liquid a sheet of metal or any object whatever of any size or shape, there would be a pressure of 2 pounds on each square inch of its surface. Or, if we think of any two parts of the liquid as separated by an imaginary plane moving in any direction, then upon each side of this plane there will be a pressure of 2 pounds to the square inch. The pressure is thus the same through all parts of the liquid, and at every point it is equal in every direction.

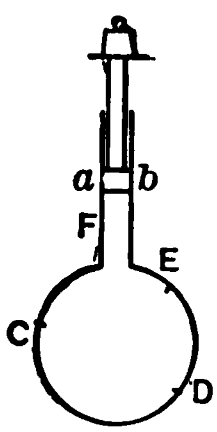


FIG. 83.

Of course, you can see that it must be equal in every direction; for if it were greater in any one direction than in another, then there would be an unbalanced force, and the liquid at that point would move in the direction of that force. But we are considering a liquid *at rest*. Hence the pressure must be equal in all directions. For the same reason, too, it must be equal at all points of the liquid. If it were less at one point than at another (leaving out of consideration the effect of weight), there would be motion toward the point where the pressure was less.

In order to understand how pressure is transmitted according to this law, let us imagine what takes place among the molecules. Remember that the number of molecules is enormously large, and that they are excessively minute, so that we never perceive anything but the average effect of a vast number of them. We have seen (page 57) how a continuous force or pressure on a surface can be produced by a bombardment of balls or molecules. The pressure of liquids or gases upon the walls of the vessels inclosing them is of this nature, being due simply to the battering of those surfaces by the molecules of the fluids. The molecules strike the surfaces and rebound with equal velocities, but in a reversed or changed direction. This reversal of the direction of their momentum produces the pressure—i. e., the tendency to acceleration—on the walls.

If the number of molecules happens to be greater in a given volume near one point of the surface, then the number of molecules striking upon the surface in a unit of time is greater, and therefore the pressure is greater; or if the velocity of the molecules is increased, each will strike a harder blow, and thus the pressure will be greater. If the pressure is increased at any point of the liquid, as by pressing harder on the piston *a b*, in Fig. 83, then the molecules become more crowded together at that point, and therefore strike harder against their neighbors, and these in turn against theirs, forcing them back in all directions until the pressure is equal everywhere. If you think of the pressure always as caused by this battering or bombarding of the molecules, and of its transmission through the liquid as due to the jostling of the molecules against one another, you will find it easier to comprehend many of the phenomena.

The Equal Transmission of Pressure in all Directions may be illustrated by simple experiments. If, in an apparatus such as that of Fig. 82, holes are made at any points, the liquid will be forced out. With a suitable measuring instrument attached to each of the holes, the same pressure will be indicated. If the finger be placed over the end of the water-faucet, the jet can be made to play equally in any direction. Through holes in the garden hose the

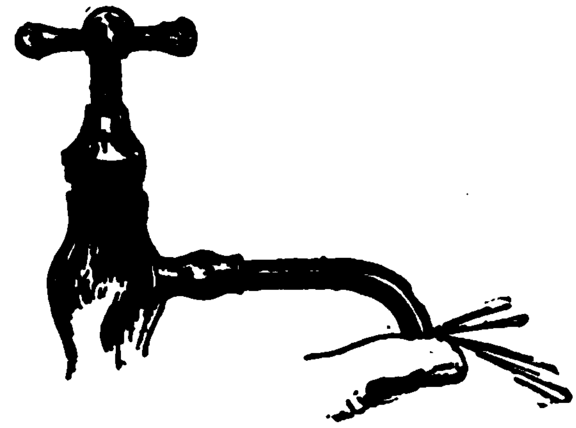


FIG. 84.

water will pass out with equal force upward, downward, or sidewise.

Pressure per Unit Area.—Intensity of Pressure.— In the case of liquids and gases, we have to deal with pressures distributed over considerable areas. Hence, when we wish to be definite, we must speak of the amount of force on a unit area. This is called the *intensity* of the pressure, or more often merely "the pressure."

The *total pressure* on any surface will then be equal to the intensity of the pressure multiplied by the area of the surface. For instance, if the intensity of the pressure is 5 pounds per square inch, and the surface acted upon is 10 square inches, the total pressure is $5 \times 10 = 50$ pounds. This is clear when you think that the pressure depends only on the number of particles battering the surface, which would naturally be twice as great with twice the surface, three times with thrice the surface, and so on.

Pressure due to Weight of Liquid.—In the case of the vessel full of shot (Fig. 20, page 73), you can understand that the upper layer would press upon the second with a force equal to its weight, the second on the third with a force equal to the sum of the weight of the first two, and so on. Imagine now the shot to be liquid molecules flying about in all directions, and thus perfectly free to move. You will then see that the particles will press against the side at any point just as hard as they press downward at the same level; that is, the intensity of the pressure will be the same on the side of the vessel as in a downward or any other direction. Where the depth is twice as great, the intensity of the pressure will be twice as great, etc.; that is, the intensity of the pressure is proportional to the depth.

The greater intensity of pressure may be pictured as due to a greater bombardment of molecules. This arises from the compression of the liquid, which, although slight, is enough to bring into each unit of volume of the liquid an enormous number more of molecules, and thus to produce the increased number of blows on the unit of surface.

At great depths, the pressure of water becomes immense; for this

reason, divers do not care to descend more than a hundred feet. Glass bottles, empty and tightly corked, are often let down with cords at sea, and the pressure is generally sufficient to crush them at comparatively slight depths. If the bottles do not break, the corks are driven in or water is forced through the pores. When a ship goes down at sea, her timbers are seldom seen again. By reason of the great pressure, capillarity, diffusion, etc., the pores of the submerged wood become filled with water instead of air. Hence, since the solid portions of wood are denser than water, the sunken vessel can not rise.

The Intensity of the Pressure does not depend on the Form of the Vessel, but only on its depth; for, if any molecule is pressed upon, it transmits the pressure in all directions. If the pressure of the first layer is transmitted to any one molecule of the next, then such molecule will jostle about until all the molecules in that layer have the same pressure. For the transmission of pressure, then, it is merely necessary that there should be some communication, however small, between successive layers.

Thus, suppose Fig. 85 to represent a cavity in the ground filled with water. The pressure at any point C will be the same—whatever the number or size of the various parts of the channel A B communicating with D—and will depend merely on the vertical depth of C below the surface. Further, the pressure on every unit of area at the same level is the same. This is true only when water is not flowing through A B, but is standing still in the entire cavity; otherwise, friction makes some difference as in all cases of motion.

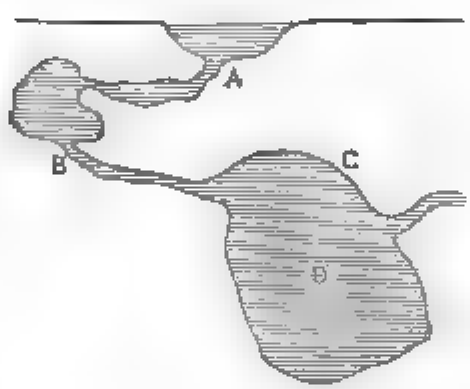


Fig. 85.—Pressure proportional to Depth.

The pressure on a unit area at C, then—say on one square foot—would be just the same as if a straight pipe, one square foot in section, passed directly upward from C to the surface and were filled with water. The pressure on one square foot at the bottom of such a pipe would be 62·5 pounds for each foot of depth—i. e., in all 62·5 × depth, for one cubic foot of water weighs about 62·5 pounds. Hence the following rules:

To find the intensity of pressure in pounds per square foot due to water at any depth, d, multiply depth in feet by 62·5—i. e., find $62{\cdot}5 \times d$.

To find the total pressure on any surface of area a at depth d, multiply intensity of pressure by area—i. e., find $62{\cdot}5 \times d \times a$.

To find the average intensity of pressure on any rectangular plane surface, multiply depth d' of middle of surface by 62·5—i. e., find $62{\cdot}5 \times d'$.

To find the total pressure on such surface, multiply the average intensity by the area—i. e., find $62{\cdot}5 \times d' \times a$.

If the liquid be other than water, use instead of 62·5 the weight in pounds of a cubic foot of the liquid. What would be the pressure per square inch at the bottom of a column of mercury 30 inches high, mercury being 13·6 times as dense as water? The cubic foot of mercury would weigh $13{\cdot}6 \times 62{\cdot}5$ pounds $= 850$ pounds. The pressure on a square foot at a depth of 30 inches $(\frac{30}{12} = 2{\cdot}5$ feet) would be $850 \times 2{\cdot}5 = 2{,}125$ pounds, or per square inch $= \frac{2{,}125}{144} = 14{\cdot}76$ pounds per square inch. How high a column of water would be necessary to produce the same pressure per square inch? As mercury is 13·6 times as dense as water, a column of water 13·6 times as high would be necessary to produce the same pressure—i. e., $13{\cdot}6 \times 2{\cdot}5 = 34{\cdot}0$ feet.

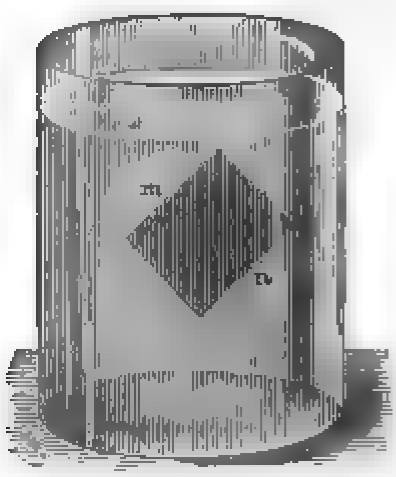


Fig. 86.—Metal Plate under Water.

It follows from the statements of this section that any pressure may be measured by the vertical height of a column of liquid which it will sustain against gravity.

Upward Pressure.—From what has been shown, it follows that if $m\,n$ represent a sheet of metal or any substance in a mass of liquid, then $m\,n$ is pressed from each side with equal force. If $m\,n$ happens to be horizontal, it will be pressed upward and downward equally by the liquid. If it is vertical, it will be pressed

equally to right and left, and so on. The pressure on either side would be perceptible, if we could remove the pressure from the opposite side.

This may be accomplished by the arrangement shown in Fig. 87. The ground glass attached to the string fits the lower surface of the tube closely. Hold the plate up by the string against the tube, and thrust the whole nearly to the bottom of the water. Then let go the string, and the upward pressure will hold the plate against the tube. If the tube be raised, the pressure will gradually diminish, until near the top it becomes too slight to support the weight of the plate, which, therefore, drops off. Hold an empty bottle neck upward in the hand and press it down in water. You will perceive very much better than by the foregoing experiment how much pressure there is upward on the bottom of the bottle, and how the pressure increases as you push the bottle down.

FIG. 87.—UPWARD PRESSURE APPARATUS.

The Upper Surface of a Liquid at Rest is level.—If C P D (Fig. 88) be the surface of a liquid standing in any receptacle, and not level, then any point P will at once begin to move, for it is acted upon by its weight in the direction W. This force may be resolved into two components, A and B, the latter perpendicular to the surface at the point, and therefore balanced, the other tangent to the surface, and thus in a direction in which the particle P can freely move. Such action will continue until no point is higher than any other, and the surface thus becomes level.

FIG. 88.

Level in Communicating Vessels.—Let A B be any vessel having a partition E D separating it into two parts. Put the same kind of liquid into the two sides, but to a

greater height A on one side than B on the other. At any point, the partition will receive a greater pressure on the A side than on the B side, because of the greater depth of liquid. Make a hole through D E at any point D below B. Owing to the greater pressure on the A side, the liquid must be forced into the B side, and this action will continue until the pressure from A toward B and that from B toward A are equal. But this can be only when the depths of liquid are the same in both sides. Hence, when the liquid is at rest in the two communicating parts of the vessel, both surfaces must be at the same level, F G. This is obviously only a special case of the principle explained in the foregoing paragraph.

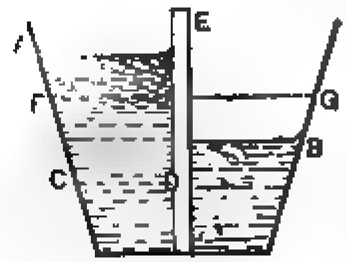


FIG. 89.—CHANGE OF LEVEL BY COMMUNICATION.

The same statement must evidently hold true for any set of communicating open vessels, whatever their form and size, as, for example, the system shown in Fig. 90. The ordinary glass water-gauge used on steam-boilers for showing the height of water in the boiler, is an application of this principle.

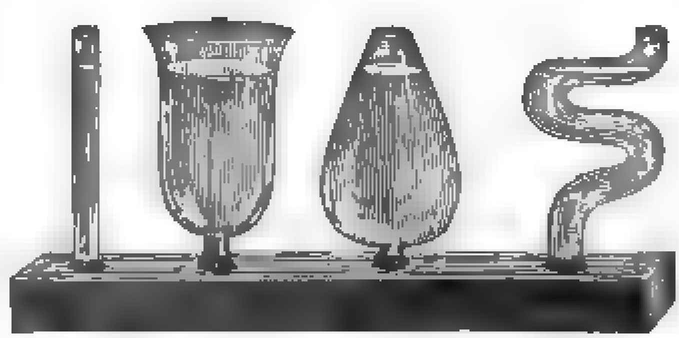


FIG. 90. EQUILIBRIUM TUBES.

The law that *water seeks its own level* is not true for vessels in which the elevation or depression due to capillarity is perceptible, or for tubes in which friction interferes with the free flow of the liquid.

The Spirit-Level is an instrument used by surveyors, carpenters, masons, and others, and in scientific work by physicists and astronomers, to adjust lines or surfaces. It consists of a glass tube nearly filled with alcohol, or a mixture of alcohol and ether, so as to leave sufficient air to form a small bubble. The tube is then sealed, and mounted in a suitable wooden or metal case.

The mounted level is then marked with a scale upon its top, so that, when the base is perfectly horizontal, the air-bubble will rest in the middle of the scale. If the bubble comes to rest in any different position, it shows that one end of the glass tube is higher than the other, and consequently that the surface on which the instrument stands is not level.

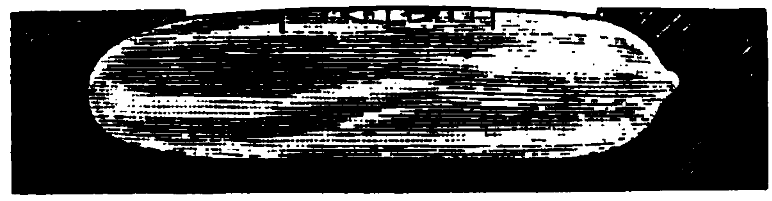


FIG. 91.—SECTION OF SPIRIT-LEVEL.

Hydraulic Press.—Let A B and D G, Fig. 92, be two upright cylinders communicating by a small tube C, and containing water or other liquid. Let A and E be pistons working without leak in the cylinders. Neglect for the present the effect of friction and the weight of the liquid. Assume the area of A to be one square inch, and that of E to be one hundred square inches. Suppose that A is forced down one inch. Then E must rise just $\frac{1}{100}$ inch; for by forcing down A one inch, one cubic inch of liquid is forced into D, and E must rise sufficiently to admit this cubic inch, or, as its area is 100 square inches, it must rise $\frac{1}{100}$ inch. Then, by the principle of conservation of energy, if a load of 1 pound is put on A and descends through 1 inch, it will be just capable of moving E up $\frac{1}{100}$ of an inch, if its load is 100 pounds.

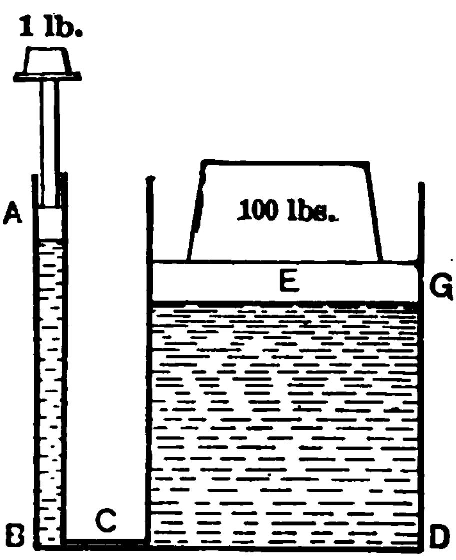


FIG. 92.—PRINCIPLE OF HYDRAULIC PRESS.

In general, the total force produced by E is to that exerted upon A as the area of E is to that of A; for let s be the distance through which A descends, and f the load upon it, and let S be the height through which E rises, and F the load upon it. Then $f \times s = F \times S$, fs being the work done *by* f, and FS the work done *against* F $\therefore F : f = s : S$. But if a is the area of A, and e that of E, it may be shown as above that $s : S = e : a \therefore F : f = e : a$. That is, the forces are proportional to the piston areas.

This arrangement, then, constitutes a machine by which we gain a mechanical advantage similar to that of the lever. We may, by making a small force work through a long distance, produce a great force which will do an equivalent amount of work through a short distance.

Such is the Principle of the Hydraulic Press, which, by the use of levers and a small piston on the pump, and of a large piston at E, is made to give total pressures of many tons. It is extensively used for lifting exceedingly heavy weights, for compressing cotton and hay into bales, for extracting the juices from cotton-seed, etc.

Fig. 93 illustrates a hydraulic press of great power. By inspecting a railroad car, you will see that the wheel is firmly attached to the axle and turns with it, the bearing being on a prolongation of the axle outside the wheel. The wheel is secured in place upon the axle by making the latter about 0·01 inch larger in diameter than the corresponding hole in the wheel, and forcing it in by great pressure. When thus joined, they hold together almost as solidly as if of one piece of

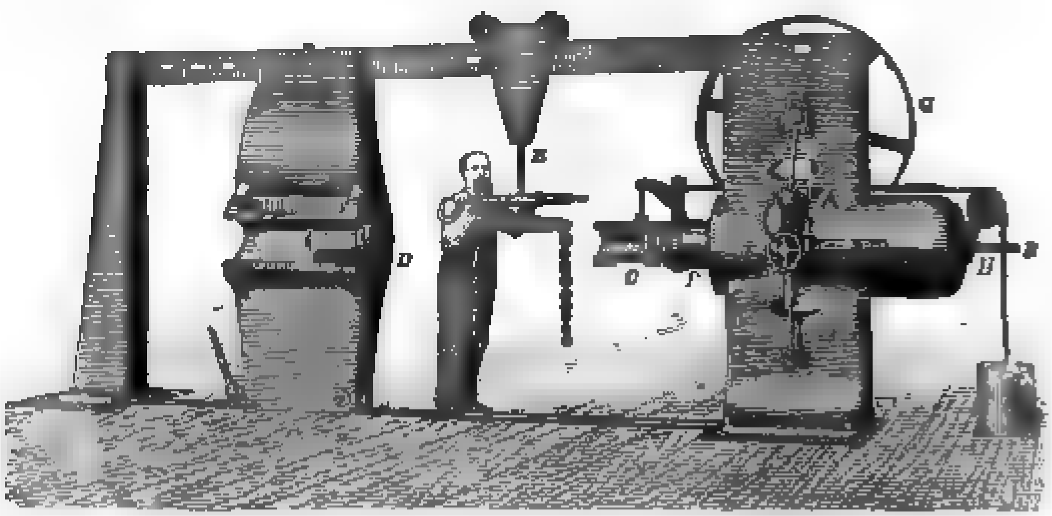


FIG. 93.—SELLER'S HYDRAULIC WHEEL-PRESS FOR LOCOMOTIVE DRIVING-WHEELS.

metal, and are said never to come apart in use. The axle is suspended horizontally between C and D by a chain from the carriage E. The wheel is held in place at the end of the axle at D, and the press set to work. The pulley G is driven by a belt from a steam-engine, and works the pump A F. This forces oil, under great pressure, through the small tube B, into the rear of the cylinder H, thus driving out the large piston P with a total pressure equal to the area of its section mul-

tiplied into the intensity of the oil-pressure as indicated by a gauge. Machines of this sort are in use which can produce pressures of 200 tons. They are employed, as well, for forcing the great driving-wheels of locomotives on to their axles.

In Fig. 94 is shown another form of hydraulic press, used for compressing the loose cotton, as it comes from the fields, into bales for transportation. The cotton is fed in at A, near the top. When the tall receiver is full, the piston, just fitting the receiver, and seen through the opening in its lower part, is forced up, thus greatly reducing the bulk of the loose cotton. This piston is the upward extension of the piston of a hydraulic press located below in the brick well. The pipe B conveys the oil, under pressure, from the pump to the press.

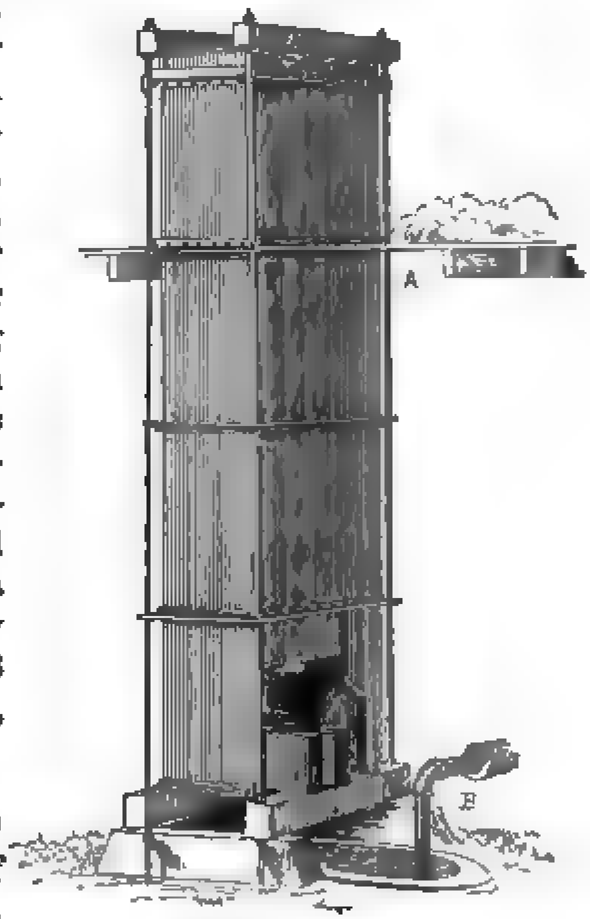


FIG. 94.—HYDRAULIC COTTON-PRESS.

That the Pressure due to a Column of Liquid depends on the Depth and not on the amount of liquid in the column, may be illustrated by such an experiment as this:

EXPERIMENT.—Into a water-tight cask fasten a small tube (of glass or eighth-inch gas-pipe, or even a thick-walled small rubber tube) rising to a height of 10 feet or more above the cask. Fill the cask with water, and then pour water into the tube. Although the cask is very strong, it will be burst by the internal pressure when the water-column is only a few feet high. Of course, the weight of the water in the column would be entirely insufficient for this. But the pressure on every square inch of the interior of the cask is that due to a water-column of this height, and it depends only on the height, and not at all on the size or shape of the column.

Similar effects may be produced in nature, as in the case of a mass of rock through which runs a long crevice, communicating with

a large cavity below, full of water, and having no outlet. When a shower fills the crevice, so great a pressure may be generated as to rend the rock in fragments. Draw a diagram illustrating this.

QUESTIONS.—State the hydrostatic law of the transmission of pressure. Describe the experiment illustrating it. How is liquid pressure and its transmission explained on the molecular hypothesis? What is meant by the intensity of liquid pressure? By total pressure? In a large, closed vessel, full of water, a pressure is exerted on a square inch, at one point, of 10 pounds; what will be the pressure on a surface of a square foot anywhere else in the vessel, neglecting the weight of the liquid? Suppose a tank to be full of water; is the intensity of the outward pressure on the side of the tank the same for all points in a horizontal line? In a vertical line? Why?

According to what law does the intensity of the pressure increase with the depth? Illustrate by the tumblerful of shot. Give the rules for finding the intensity of water-pressure at any depth. For finding the average intensity of pressure upon a given surface. For finding the total pressure on that surface. If the liquid be something other than water, how are these rules changed?

What would be the intensity of the pressure at a depth of 1,000 feet in fresh water? In salt water of a density of 1·03? What would be the total pressure, there, on the top of a box 2 by 4 feet?

Show by experiment that in a mass of water there is upward as well as downward pressure. Show that there is pressure in all directions. Why does the surface of water assume a "level"? Is the surface of water at rest truly plane? If not, what is its shape? *No matter what the size or shape of a body of water may be, its surface has the same level throughout—that is, it is equally distant at every point from the earth's center. Accordingly, the surface of the ocean is spherical; and this we know to be the case from always seeing the mast of a vessel approaching in the distance before we see the hull. The convexity is so slight, however, that in small bodies of liquid the curvature is imperceptible, and we may consider their surfaces as perfectly flat.* Show why water in communicating vessels stands at the same level. Would this be true for vessels of unequal sizes, but so small that capillarity affects them? Describe the principle and use of the Spirit-level.

Explain the principle of the Hydraulic press. If the large piston's area is 200 inches and that of the small one 0·5 inch, how much is the pressure on the large piston for 1 pound on the small one? Suppose the small piston is worked by a lever of the second order, with a leverage of 10, and a power of 100 pounds is applied at the lever end, what will be the lifting force on the large piston, neglecting friction, etc. Suppose the press worked thus by a man, how much gain of work is there over what the man can do? What is the kind of advantage gained by using the press? How much is the gain? Deduce the law of action of the press by applying the principle of the conservation of energy. By means of the law of hydrostatic pressure. What are some of the practical applications of the press? Describe the wheel-press; the cotton-press. Explain the experiment of bursting a cask by a small weight of water. What similar effect is produced in nature?

BUOYANCY OF LIQUIDS.—SPECIFIC GRAVITY.

A Body submerged in a Liquid appears to lose a part of its weight, the amount lost being equivalent to the weight of an equal bulk of the liquid. This is called, from its discoverer, the Principle of Archimedes.

EXPERIMENT.—Tie a string to a stone. Hold the end of the string in your hand and lower the stone into water. Notice that when the stone begins to enter the water it appears lighter in weight, and that it continues to lose weight more and more as you lower it until it is all immersed. It then appears of the same weight, whether just under the surface or at any greater depth. Instead of a string use a rubber band, and notice how it shortens as the stone goes under water; or, better still, attach the stone to a spring-balance. A stone so heavy that you can hardly lift it in the air can be easily moved under water, for its apparent weight will be only half or two thirds as much as its real weight.

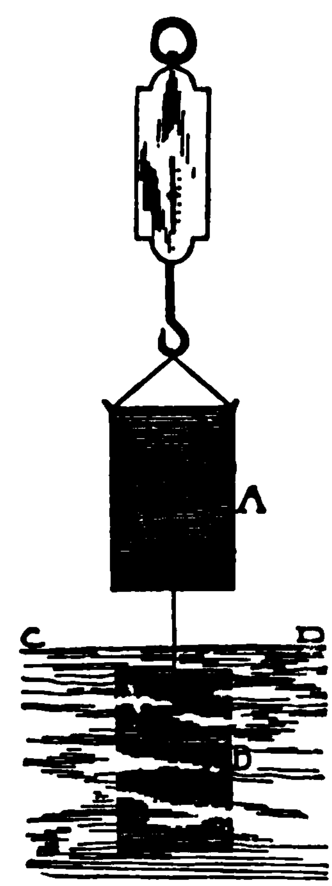


FIG. 95.—PRINCIPLE OF ARCHIMEDES.

When under water, the body must, of course, thrust aside, or displace, a volume of water equal to its own bulk in order to make room for itself. The apparent loss of weight is equal to the weight of water displaced. This may be experimentally shown as follows:

Let A (Fig. 95) be a tin vessel open at the top, and B another which exactly fills A but which has a water-tight top soldered upon it and lead enough inside to make it sink. Hang them upon a spring- or equal-arm balance and read the balance. Then lower B into water until it is wholly submerged, so that the water surface is at C D. The balance will read less, showing that B has apparently lost weight. Pour water into A until it is just full. You will have added a volume and weight of water exactly equal to that displaced by B. The balance will be found to read the same as before B was immersed. Hence the apparent loss of weight of B is just equal to that of its own volume of water. The same experiment may be tried with any other liquid.

This loss of weight is apparent, not real. The cause of the difference is not that the attraction between B and the earth is lessened, but that B is pushed upward by another force which partly counterbalances its weight. This lifting force is due to the pressure of the liquid, and is called the Buoyancy of the liquid. The downward pressure of the liquid on the top of B is that corresponding to its depth. The upward pressure on the bottom is that corresponding to its greater depth, and is therefore greater than the downward pressure, so that the resultant pressure is upward.

Suppose the body were a cube in water with its sides vertical. The downward pressure on the top would be $62{\cdot}5 \times \text{area} \times \text{depth of top}$. The upward pressure on the bottom would be $62{\cdot}5 \times \text{area} \times \text{depth of bottom}$; but area of top = area of bottom, and the depth of bottom is greater than that of the top by the length of the side. Hence pressure on bottom − pressure on top $= 62{\cdot}5 \times \text{area} \times \text{length of side}$. But area × length of side = volume of cube, and therefore $62{\cdot}5 \times \text{area} \times \text{length}$ = weight of water equal in volume to the cube. The buoyancy is then equal to the weight of an equal volume of water. It is obvious that the buoyancy will not vary with the depth, since it depends only on the difference of depth of the top and the bottom of the cube, which is always the same, and on the weight of a cubic foot of water which changes but slightly with the distance below the surface. Liquids denser than water will produce a greater, those less dense a less, buoyancy. For such, instead of 62·5 we must write their weight per cubic foot. A similar proof holds for bodies of any form, since they may be regarded as made up of a large number of very minute cubes, to each of which this demonstration will apply.

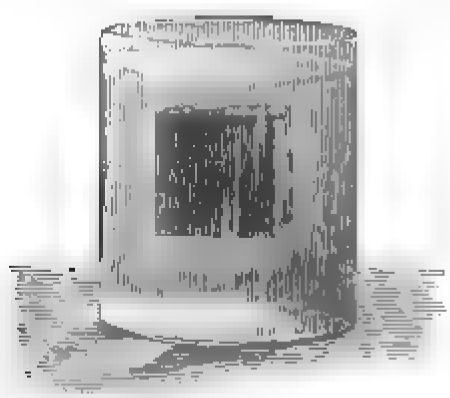


FIG. 96.—IMMERSED CUBE.

Floating Bodies.—If a body floats when put into water, it displaces a weight of water just equal to its own weight. Place any substance, for example, a piece of wood, in water; you will see that part of it is beneath and part above the surface. In order that it may float, the body must

be buoyed up by a force equal to its weight. But the buoyancy is equal to the weight of the water displaced by the immersed portion, as shown above. Hence, when floating, a body must be displacing a weight of water exactly equal to its own weight.

Any solid or liquid less dense than water—e. g., oil—if entirely immersed in water will be buoyed up by a force greater than its own weight. Why? It will therefore tend to rise through the water and float on top. Warm water is less dense than cold water, therefore it will tend to rise in currents through the cold water. In a glass vessel heated at the bottom, you can see these currents. Cream is less dense than milk, and therefore rises. It is to be noted that we speak of these things as *rising*, although they really do not rise of themselves but are forced upward by the upward pressure due to the excess of weight of the heavier liquid surrounding them.

With the lungs full of water or entirely empty of air, the human body is probably slightly denser than water. When the lungs are full of air, it is less dense than water, so that it will rise to the surface without effort on the part of a swimmer. But the head is more dense than other parts, so that some slight effort is generally necessary to keep the head at the surface. In swimming in the usual position, more of the head is kept out of water than the buoyancy can sustain. Hence, effort is necessary for this purpose as well as for propulsion. In floating on the back with barely just enough of the face out for breathing, no effort is required except a very slight one with the hands to preserve the proper position of the body. The knowledge of how to float thus upon the back with very little effort and to breathe when the head is in the troughs between waves, might save many lives in accidents on the water. Notice some time, when bathing in shallow water, how light the body appears if wholly immersed, and how fast it seems to grow heavy as you rise out of the water to a standing posture. This will easily convince you of the great waste of effort you would make in swimming or floating if you were to try to keep out of water more than just enough of the face to enable you to breathe.

Density, or Specific Gravity.—Application of the Principle of Archimedes is made to determine the relative densities of bodies. Density is the mass per unit volume. In scientific work, the density is expressed in grammes per cubic centimetre; that of water is almost exactly one gramme

per cubic centimetre. In engineering and commercial work, densities are not usually stated in units of mass, but the density is given relatively to that of water taken as a standard. This relative density is called Specific Gravity; it is more properly Specific Density, or merely Density. By specific gravity, then, is meant the ratio of the mass of any volume of the given substance to the mass of an equal volume of pure water at a standard temperature. As the mass of a cubic centimetre of water is 1 gramme, the specific gravity of a substance referred to water, and its density in grammes per cubic centimetre, are numerically the same.

Methods of measuring Specific Gravity.—Weigh the body whose specific gravity is to be determined in air, and then when hung in water, as in Fig. 97. The difference in weight will be the loss of weight in water, which is the weight of an equal bulk of water. Divide the weight in air by the loss of weight in water. The quotient will be the specific gravity.

Fig. 97

To find the specific gravity of a liquid, like a solution of salt, weigh a glass-stoppered bottle when empty and dry, again when completely filled with the liquid, and a third time when full of water. Subtracting the weight of the bottle when empty from each of the other weights, will give the weights of equal volumes of the liquid and of water. The quotient of the first by the second will be the specific gravity desired. A similar method with the bottle may be used for solids.

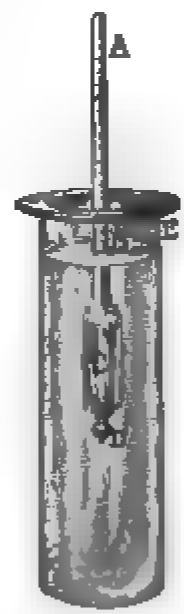


Fig. 98.
Hydrometer.

The Hydrometer.—The specific gravities of liquids are also determined readily, when very great accuracy is not required, by means of the Hydrom'eter, one form of which is shown in Fig. 98.

A hollow glass bulb is weighted slightly with shot or mercury at the lower end, D, and is prolonged upward into a thin tube, A. In-

side of this tube is a paper scale, A B. When the hydrometer is immersed in water, as shown in the figure, it settles to such a depth that the reading on the scale at the water surface B is 1. If it is immersed in a less dense liquid, it will sink deeper, and the reading at the liquid surface will give the specific gravity of the liquid referred to water. If it is immersed in a liquid denser than water, it will sink less deep, and the reading will again give the specific gravity of the liquid. Certain hydrometers are graduated to give specific gravities directly; some, with an arbitrary scale; and others, for special purposes, such as testing milk, showing the strength of an alcoholic mixture, etc. The depth to which the hydrometer will sink in the pure article being known, any different result, when a liquid is tested, indicates adulteration.

TABLE OF DENSITIES OR SPECIFIC GRAVITIES.

Platinum	22·0	Water	1·00
Gold	19·4	Olive-oil	0·92
Mercury	13·6	Average density of human body	0·89
Lead	11·4	Alcohol (absolute)	0·79
Silver	10·5	Wood (pine)	0·66
Brass	8·4	Cork	0·24
Iron	7·5	Air	0·0012
Average density of the earth	5·67	Hydrogen	0·000088
Marble	2·8		

Flow of Water.—Let A B (Fig. 99) be any reservoir of water kept at a constant level A. Suppose a pipe to lead from it at C along to D E F G L. Let D H, E I, etc., be open vertical glass tubes. At first suppose D L to be a straight uniform horizontal pipe. Now, if this is closed at L, the water will flow out of C until the pipes D H, E I, etc., are all filled up to the level H I J K, which is the same as A. But if L is opened, the water in the glass pipes will drop to some such points as H′, I′, J′, K′, although A remains the same. Why? The heights of liquid D H′, etc., are supported by, and thus measure, the pressures in D L at the points D, E, F, G. When there is no flow, the liquid is at rest, the pressure must be the same throughout D L, and the heights D H, E I, etc., must all be the same. When the water is flowing out at L, it has to overcome friction on the sides of the tube and upon itself.

If any of the vertical pipes were removed from the pipe D L, the water would issue from the opening as a jet or fountain, which would rise as high as the water formerly stood in the pipe. For instance, if E I were removed, the fountain at the point would rise to the height I if L were closed, or to I′ if L were open. This statement, however, needs modification; for the jet would meet with some air resistance which would reduce its rise, and the extra rate of flow through the pipe C D E required to supply the quantity escaping at E, and also the friction of the orifice, would somewhat reduce the pressure, and hence the height of the fountain.

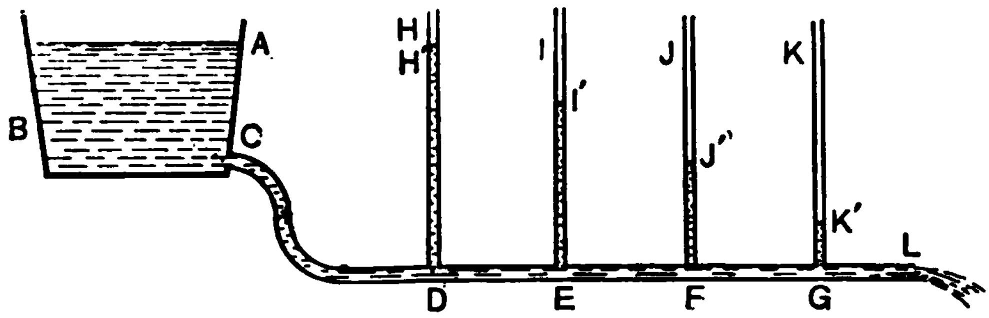


FIG. 99.—FLOW OF WATER THROUGH PIPES.

At L the pressure is only such as to give the water the energy which it acquires on leaving L. At G the pressure must be greater than at L by an amount necessary to do the work of driving the water through G L against the friction. At F it must be greater still by the amount necessary for the work in F G, and so on back to the source C. The resistance to flow through pipes is due partly to friction, partly to other causes; it increases with increase in length of pipe, roughness of interior, number of joints, number of bends or turns, angle of bends, number of irregular enlargements or contractions of pipe, and rate of flow. It diminishes with increase of diameter of pipe proportionally to about the fourth power of the diameter. Similar statements apply to the flow of gases through pipes, as in ventilating apparatus. These laws find very important practical application in water-supply and sewerage systems, in heating and ventilating apparatus, in steam piping, and in hydraulic work generally.

Water in the Soil.—Water is also continually flowing through the soil, in some places along regular underground channels, but more generally in a steady flow or percolation. Fig. 100 may serve to give some idea of this. Let A B C D represent the surface of the ground shown in a vertical section, and suppose the soil to be a uniform gravel or sand, sloping off to a lake at D E. Then the soil would be generally found to be *filled* with water below a certain depth indicated by the shading below F G H I D. This water

surface would be somewhat definitely marked, but, of course, not perfectly sharp, as the soil above it would be damp. The water below it would be continually flowing in a mass toward the lower level, but the flow would be quite slow, owing to the resistance to flow through the soil. The source of this water is the rain falling upon and soaking into the soil, and the surface F G I is lower after dry and higher after rainy times. Most soils are not uniform, but contain ledges, or strata of clay, sand, or gravel. These strata greatly modify the actual distribution of water. Artesian wells, intermittent springs, etc., owe their action to such peculiarities of soil formation.

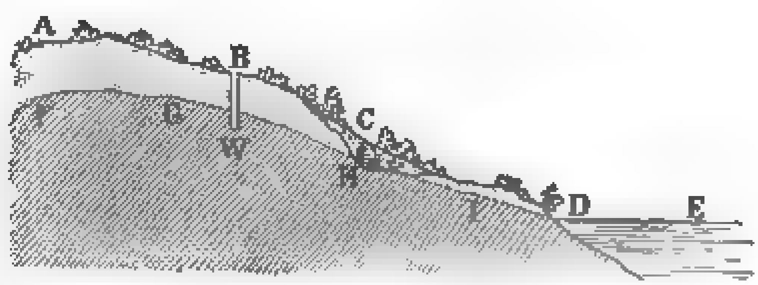


FIG. 100.—FLOW OF WATER IN THE SOIL.

If at any point H the ground shows a natural depression below the surface F G I, there will be a Spring or a standing pool at that point. If a hole be dug, as at B W, until it is below the water surface, it will contain water up to that surface, forming a Well. If the well is so deep that the ground-water surface is never below its bottom, the well will never be dry.

QUESTIONS. What is meant by the buoyancy of a liquid? How much does a body immersed in water appear to lose in weight? How much would it appear to lose in mercury? In any other liquid? In any other fluid? Show this by experiment. Describe an experiment to prove the principle of Archimedes. Prove the principle for a cube immersed in water by means of the law of hydrostatic pressure. Prove it for a body of any form whatever Why does a piece of wood tend to rise when wholly immersed in water? With how much force?

What enables some objects to float? How much liquid does a floating object displace? Why will iron float on mercury but sink in water? Why will oil float on water but sink in alcohol? About three quarters of the mass of the human body is water; of the remaining parts much is more dense than water. How, then, is it possible that the body, on the whole, is less dense than water? If a person is about to dive and wishes to return as quickly as possible to the surface, why should he thoroughly inflate his lungs? How does your experience in rising out of water illustrate the buoyancy of liquids?

Define Density; Specific Gravity Why are the density in grammes per cubic centimetre and the specific gravity referred to water numerically the same? What is the density of gold? Of water? Of air? Describe a method for find-

ing the specific gravity of a solid; of a liquid. Given a block of iron 1 inch long, 2 inches wide, and 3 inches high, how could you find its density without immersing it in water or wetting it? How should you suppose the density of a gas might be determined? A piece of unknown material whose weight is 23·5 grammes is found to weigh 20·15 grammes in water. What is its specific gravity? What is its density? Refer to the table on page 197 and see what the substance probably is.

What is the weight of a cubic foot of water? Of iron? of air? What is the volume in cubic feet of a ton of water? Of a ton of iron? Describe the flow of water through pipes by means of Fig. 99 (page 198). What factors affect the resistance of pipes to the flow of liquids? Why is a pipe of twice the area of section more than twice as good? Why is a straight pipe better than a crooked one? A short one than a long one? A large one than a small one? One with a smooth interior than one with a rough interior? One with few joints and turns than one with many? Do these statements apply also to chimney-flues? To ventilating flues? Would a chimney "draw" well out of a room into which no air could enter? Where do you suppose the air enters a room when all the doors and windows are closed?

Describe the simplest case of the distribution and flow of water in a uniform sand-hill. If in Fig. 100 there were a horizontal layer of clay across the hill one quarter way up from the lake, where should you expect to find springs?

GASES AND THEIR PROPERTIES.

Gases have Weight.—We easily perceive the weight of most solids and liquids because they weigh more than the air displaced. You will see, however, on reflection, that we can not weigh water in water, as the quantity to be weighed would be buoyed up by a force equal to its own weight. For a similar reason we are not sensible that air has weight, for we ordinarily weigh bodies in air, and air weighed in air would appear without weight; try the following.

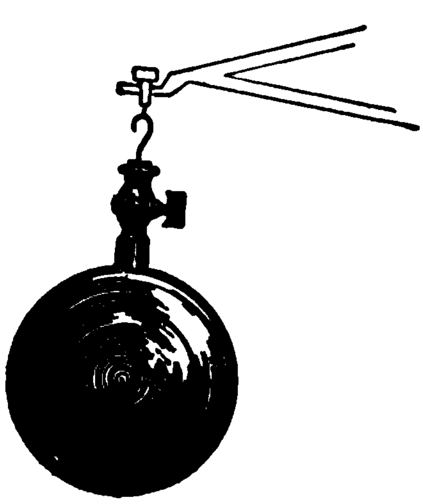


FIG. 101.

EXPERIMENT.—Hang the hollow globe of Fig. 101 on one arm of some moderately sensitive balance, and counterpoise it by sand or any weights in the other pan. Then take off the globe and exhaust the air with the air-pump or by sucking it out with the mouth. Close the stop-cock and again hang the globe on the balance, the same weight remaining in the other pan. The balance will now tip, showing the globe to be much lighter. Why? Nothing has been changed except that air has been taken out

of the globe. The weight is less. Therefore the air removed must have weight. In a similar manner, other gases may be shown to have weight.

A litre of air weighs only 1·2 grammes at ordinary temperatures and pressures, while a litre of water weighs 1,000 grammes, so that the density of air is only about $\frac{1}{800}$, or roughly $\frac{1}{1000}$, of that of water.

Atmospheric Pressure.—The earth is surrounded on all sides by a layer of air several miles deep called the Atmosphere. As this air has weight, it must press down upon the earth's surface and everything on the earth just as the water does on the ocean-bottom and on all submerged objects. At sea-level, the pressure of the air is in all directions about 15 pounds to the square inch. We may show the existence of such pressure by several experiments.

EXPERIMENTS.—Fig. 102 illustrates the "Magdeburg Hemispheres"—hollow metal hemispheres, with their edges carefully ground and greased. Put them together and you can pull them apart easily, whether the cock is open or closed; but put them together and exhaust the air partly from within them (by air-pump or mouth) and close the cock. You will then find it very difficult to pull them apart in any direction. Why? Because the atmosphere, owing to the pressure produced by its weight, is forcing them together on all sides.

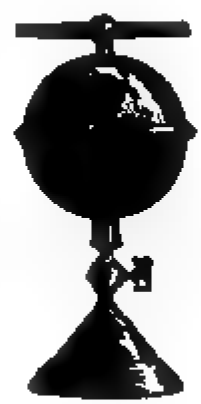


FIG. 102. MAGDEBURG HEMISPHERES.

Over the top of a glass vessel like that shown in Fig. 103, stretch a piece of thin sheet rubber. Place the glass upon the plate of the air-pump. The rubber will be flat. Exhaust some of the air. The rubber will begin to bulge inward. Why? Because the atmosphere presses down upon it. But this was also the case before the air was removed; why did the bulging not occur then? Because the pressure was balanced by the upward pressure of the air beneath. Instead of the glass shown, a lamp-chimney, with a rubber stopper in one end and the sheet rubber over the other, may be used. The air may then be removed by sucking with the mouth upon a glass tube passing through the stopper. The

FIG. 103.—TO ILLUSTRATE ATMOSPHERIC PRESSURE.

same result will be reached if the rubber surface is downward, sidewise, or in any position, showing that the atmospheric pressure is exerted in all directions. If the palm of the hand is put in place of the rubber sheet, it becomes bulged inward when the pressure is removed from beneath it.

FIG. 104.—ILLUSTRATING DOWNWARD ATMOSPHERIC PRESSURE.

Place a thin green leaf over the lips and draw in the breath strongly. The leaf will break in with a snap. Why?

Over the top of an argand chimney, or any other glass tube, tie a bit of thin sheet rubber. Place the whole sidewise under water and fill it. Then invert it as shown in Fig. 104. The rubber is drawn in more and more the higher it is above the water outside the tube. When the rubber is level with the water outside, it is flat. Why? Because the water column below the rubber transmits the atmospheric pressure to the under side of the rubber, and the upward and downward pressures are equal. But as the tube is raised, the water column itself balances part of the atmospheric pressure, so that the upward pressure on the under surface of the rubber is less than the downward pressure on the top.

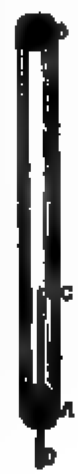


FIG. 105.

Put a tumbler under water and fill it. Then draw it out bottom upward. Notice what happens and give the reason for it. Does the tumbler feel heavier? Why? How much?

A glass tube A B (Fig. 105) is closed at both ends by stoppers. Through the lower stopper passes a small tube D C drawn out to a fine open point at C. Suck out as much of the air by the mouth at D as you can. Then close D with the finger, thrust the lower part of the apparatus under water, and observe what occurs. Explain the action.*

The Barometer.—Melt together in the gas-flame the end of a clean, dry, glass tube, three feet long and one eighth to one fourth inch inside diameter. Fill it with mercury. Bubbles of air will adhere all along the inside of the tube. To get rid of these, leave a quarter of an inch of the tube at the open end empty. Put the finger over this end and turn

* This and some other simple apparatus will be found described in Hopkins's Experimental Science, Munn & Co., New York.

the tube into a nearly horizontal position, but with the closed end a little higher. The large bubble will run upward slowly toward the closed end, collecting the smaller ones on its way. Then raise the open end, and the bubble will run back. Repeat this operation several times, until most of the bubbles are removed. Next fill the remaining space with mercury, put the finger over the open end, and invert the tube into the position shown in Fig. 106, where B is the closed end and A is a dish of mercury. Such a tube is called a Barometer.

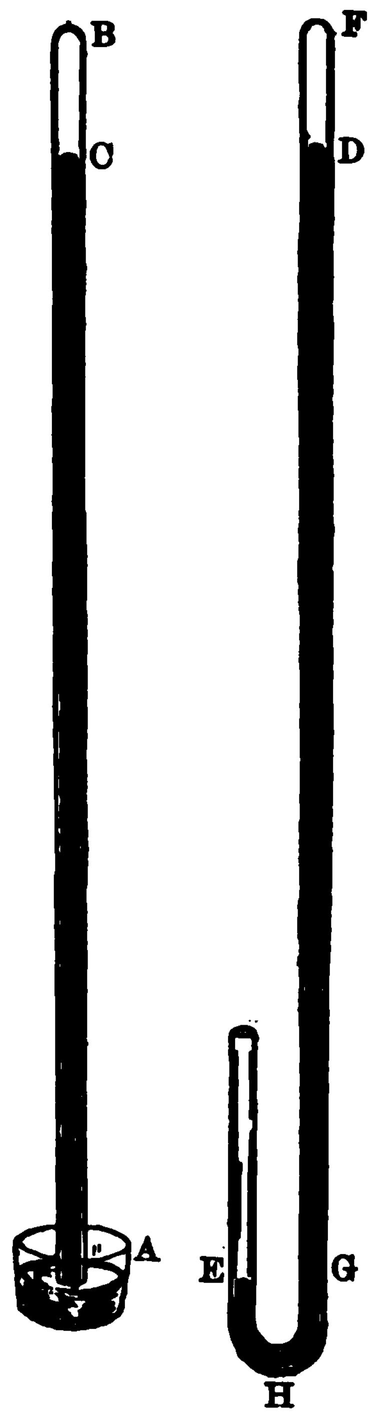


FIG. 106.—FORMS OF BAROMETER.

The mercury in the barometer will fall at once to some point C. Measure the height A C from the surface in the dish. It will be found to be, on the average, at the sea-level, about 30 inches (from 28 to 31, according to the condition of the weather). This experiment is called, from its discoverer, Torricelli, the Torricellian experiment.

Repeat with a different tube, and A C will be found the same, except for variations due to imperfect removal of air, capillarity, etc.

Why does the mercury not fall to A? Use a much longer tube; A C will be the same. Use a tube less than A C in length, and the mercury will remain up to the top. Compare this with the experiment of Fig. 103, and with the tumbler experiment (page 202). The atmospheric pressure, then, is transmitted through the mercury in the dish to the bottom of the tube, and there presses upward with a force sufficient to balance the downward pressure of a column of mercury of a height A C—about 30 inches. The barometer, therefore, measures the atmospheric pressure, and hence its name (*weight-measurer*). This pressure at sea-level (see example, page 186) is about 14·7 pounds on each square inch of surface.

If the atmospheric pressure will balance a column of mercury 30 inches high, it will sustain a water column of 34 feet, for these two columns produce equal pressure (see example, page 186). To balance

the atmospheric pressure by a water-column, we should need a tube at least 34 feet instead of 30 inches long.

If, instead of a straight tube inverted in a dish of mercury, a tube be bent into the second form shown in Fig. 106, the end F being closed and the short end open, the mercury will stand with a difference of level E D, equal to A C of the other tube.

The space above the mercury in B C and F D is called a vacuum (*empty space*). If the experiment were perfectly performed, it would contain nothing but a minute amount of the vapor of mercury. A perfect vacuum would be a space containing nothing; but such a condition can not be reached. All that we can arrive at is a space containing only a very minute amount of gases or vapors.

Uses of the Barometer.—The instruments ordinarily sold as mercurial barometers contain a tube like one or the other of those shown in Fig. 106, carefully filled with mercury, all air being removed. A scale along the upper part of the tube marks the height of the mercury. This height varies from time to time, because of changes in the atmospheric pressure accompanying changes of weather. In general, a rapid or considerable falling of the mercury accompanies a storm and a rise of temperature; while a considerable rise is usually accompanied or followed by fair and cooler weather. The weather can not, however, be predicted closely from readings of the barometer alone. Rapid and extreme changes of barometer generally indicate and accompany violent winds. The barometer is also used to measure the heights of mountains, as explained on page 225.

The Aneroid Barometer.—An instrument known as the Aneroid (*without moisture*) Barometer is very convenient for many purposes. It is light, compact, and easily carried, and thus forms a desirable substitute for the mercurial barometer, which is awkward and heavy, although more accurate.

A flat, thin-walled, circular metal box (two to five inches in diameter), with a corrugated surface, is hermetically sealed, after the air has been exhausted from within it, in order to prevent the indications from being affected by the varying pressure of this air under change of temperature. When the atmospheric pressure increases, the sides of the box are thereby forced farther inward; and when this pressure is lessened, they spring outward, the amount of motion being proportional to the change of pressure. To indicate this motion, a mechanical arrangement of levers, etc., is connected with the box in such a way that the compression and expansion move a pointer playing over a graduated dial. From this dial the pressure may be read directly.

To understand fully the principle of the aneroid, which is often carried in the pocket to determine heights above sea-level, the pupil must examine an instrument for himself.

QUESTIONS.—Prove that gases have weight. Why does the atmosphere exert a pressure on objects within it? In what direction is the atmospheric pressure? What is illustrated by the Magdeburg hemispheres. Describe several experiments illustrating the pressure of the atmosphere. Do all gases transmit pressure according to the same law as liquids? Do all fluids? What is a fluid?

Describe the filling and inversion of the tube in the Torricellian experiment. What keeps the mercury from falling inside the tube to the level of the mercury outside? If a barometer-tube were placed under the receiver of an air-pump and all the air pumped out, where would the mercury stand in the tube? Why? How high, on the average, does the mercury stand in a barometer-tube? Why does it vary in height? What is meant by a vacuum? Has a perfect vacuum ever been attained? What more does the ordinary form of barometer possess than the single tube and cistern represented in Fig. 106? Enumerate the uses of the barometer. Explain the principle of the aneroid barometer.

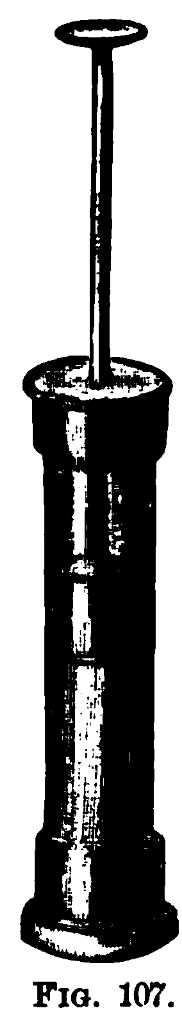


FIG. 107. PNEUMATIC SYRINGE.

COMPRESSIBILITY AND EXPANSION OF GASES.

Gases are compressible.—The pneumatic syringe, shown in Fig. 107, is a glass tube in which a tight-fitting piston can be pushed down. Air or other gas may be inclosed between the piston and lower end of the tube, with no chance for escape. Push down the piston, the air is reduced in volume—i. e, is *compressed.*

Press an empty tumbler, mouth downward, into water.

Notice that the water rises somewhat in the tumbler, compressing the air. Try the same experiment with mercury.

Law of Compressibility.—Fig. 108 shows a vertical glass tube bent at the bottom, open at the end B, and closed at D. The tube is at first full of air or other gas. A scale is placed along each branch. A little mercury is then poured in at B, thus separating the air in the closed branch, D C, from the outside air, so that no air can enter the closed branch or escape from it during the experiment. The mercury stands at nearly the same level at A and C, and therefore does not exert any pressure on the inclosed air.

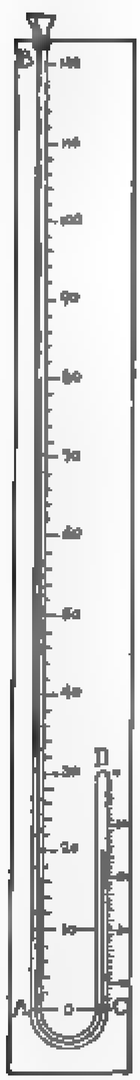


Fig. 108.

The air in D C is now under the pressure of the atmosphere at the time, for the atmosphere is pressing down on the mercury at A, and the pressure is transmitted through the mercury to the gas at C. This pressure may be assumed, for our experiment, to be equal to that of about 30 inches of mercury. Read now the heights of the mercury at A and C on the scale between the tubes. They will be nearly the same. Read also the height of the mercury at C on the scale at the right of D C. This scale is numbered from the top D downward, and measures off the volume of the air between D and the top of the mercury. Suppose, then, that A and C read 2 on the middle scale, and C reads 42 on the volume scale. Then the pressure of the inclosed air is 30 inches of mercury, and the volume is 42 units.

Pour in more mercury until the mercury in the open arm stands at a height of 30 inches above that in the closed arm—for instance, suppose that the first height is 46 and the second 16, on the middle scale, and that the reading in the closed arm is 21 on the volume scale. Then the volume has been reduced to 21. What is the pressure? The mercury column is exerting a pressure of $46 - 16 = 30$ inches, by its own weight. In addition to this, it is transmitting the atmospheric pressure of 30 inches. Hence the pressure on the gas at the level of the mercury in the closed arm is $30 + 30 = 60$ inches. The pressure, then, has been doubled, and the volume thereby halved.

Pour in more mercury until A stands 60 inches above C. Suppose

that the pressure scale then reads 79·5 inches and 19·5 inches, and that the volume scale reads 14. Then the mercury-pressure is $79{\cdot}5 - 19{\cdot}5 = 60$ inches, and the total pressure is $30 + 60 = 90$ inches. The volume is 14. The pressure has then been trebled, and the volume reduced to one third.

In general, it will be found that, however much mercury is poured in, the volume of the compressed air will be inversely as the pressure upon it, if we keep the air at a constant temperature. The law of the compressibility of gases, then, is as follows:

With a constant mass of gas at a constant temperature, *the volume is inversely as the pressure upon it.*

This law is very nearly true for all gases, but there are slight variations from it. It is called the law of Boyle, or sometimes the law of Mariotte, from the names of its discoverers.

The apparatus of Fig. 108 illustrates the law only when the pressure is greater than that of the atmosphere. Fig. 109 shows an apparatus for proving the same law for smaller pressures. A glass tube, A B, closed at the top, is filled with mercury, like a barometer-tube, and inverted in the deep cistern of mercury, E F. Then a little air is allowed to bubble up into the tube through the mercury, collecting above it as shown at A B.

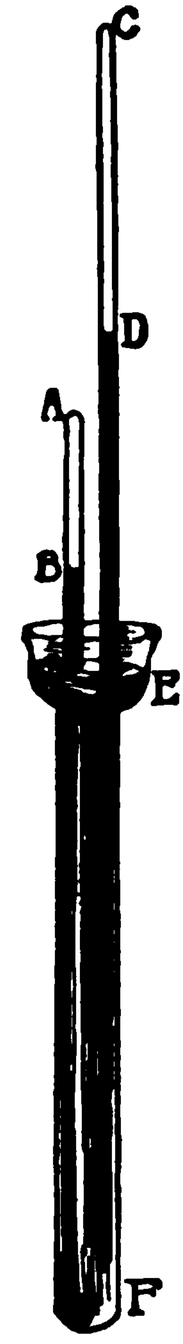


Fig. 109.

Experiment.—Push the tube down until the mercury within it stands at the same level as that outside. Then the pressure on the gas is equal to that of the atmosphere, or 30 inches of mercury. Measure the volume of the air by reading off from a scale beside or upon the tube the distance from A to the mercury surface in the tube. If, now, the tube is lowered, the air will be compressed. If it is raised, the air will expand. Raise the tube somewhat. Measure the volume A B from A to the top of the mercury column (left-hand position in the figure); also the distance from B to E, the mercury surface in the cistern. The pressure of the air is now less than that of the atmosphere by

the pressure of the mercury column whose height is B E, for the atmospheric pressure transmitted from the outside surface of the liquid in E through the mass of liquid and into the tube is balanced in part by the pressure due to the weight of the column B E. The pressure is, then, 30 inches minus B E (expressed in inches).

For example, if B E = 5 inches, the pressure is now 30 — 5 = 25 inches. Suppose the first volume was 42, then the present volume will be found to be 50·4. Now, 50·4 : 42 = 6 : 5, and 25 : 30 = 5 : 6. That is, the volume is inversely as the pressure. If the tube be raised still higher, as shown in the second position in Fig. 109, the air will expand further, and the mercury stand at a still higher point, D. Suppose that D E = 15 inches. Then the pressure will be 30 — 15 = 15 inches, or one half the original. The volume will be found to be 84—that is, double the original. Thus the same law holds; for the atmospheric pressure, under which we start to go either one way or the other, is no natural starting-point, but merely a pressure which happens to exist at the earth's surface.

In all these cases, the pressure exerted by the gas is of course exactly equal and opposite to the pressure upon the gas. Otherwise, there would not be equilibrium.

Gases expand.—We have seen how, by increasing the pressure upon them, we can compress gases. Let us study the effect of removing the pressure.

EXPERIMENT.—Close the opening of a rubber toy balloon, after allowing most of the gas to escape; or tie up the end of one of the small rubber bags used on children's toy whistles, or the end of a moistened bladder, leaving a little air inclosed. Put this under the receiver of an air-pump. The balloon is loose and lies in folds, as in Fig. 110; the air inside and outside of it is at the same pressure, that of the atmosphere at the time. Now work the pump. Notice how the balloon swells out more and more as you proceed. What is taking place? The pump removes some of the air from the receiver, thus reducing the pressure. The air pressure within the balloon is no longer balanced by that outside, and motion ensues. The air-molecules within the balloon force one another farther and farther apart—that is, the gas *expands.*

FIG. 110. EXPANSION OF AIR.

How much does it expand? Stop pumping, so that the pressure on the balloon may be constant. The air in it expands until its pressure inside the balloon is just equal to that outside, allowing of course for any elastic force produced by the rubber if it is stretched. The more you pump, the less the outside pressure, and the more the air inside must expand to reduce its pressure to equal that outside. This would continue indefinitely, either until the balloon was expanded sufficiently to fill the whole receiver, or until it burst.

Fig. 111 suggests a simpler way of performing this experiment—suck the air out of the bottle through the tube E. Fig. 112 illustrates the principle in another way. The glass bulb F full of air (an inverted test-tube will answer) is placed inside the bottle, with its open end down, and immersed in a shallow layer of water at B. C is a plug closing the second opening in the stopper. On sucking the air out of the bottle by the mouth at the tube E, the air in the bulb will expand, as shown by its bubbling through the water.

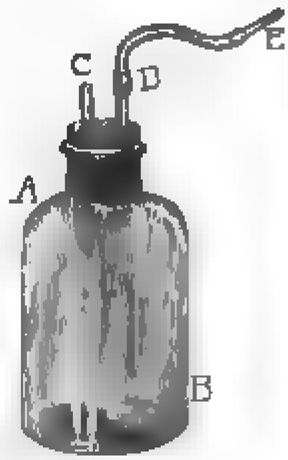


FIG. 111.

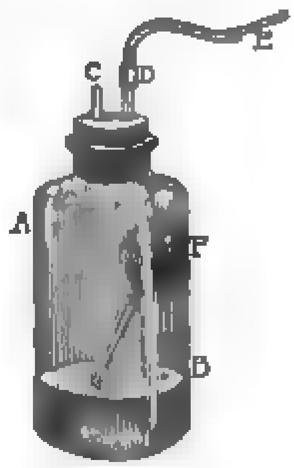


FIG. 112.

The apparatus of Fig. 109 also illustrates the expansion of gases.

Expansion will continue indefinitely—that is, a gas will continue to expand as long as we go on diminishing the pressure. Suppose we had a large air-tight box and exhausted all the air from it, so that it was really empty—i. e., was a vacuum. Then suppose we admitted a small bubble of any gas. Even so minute a portion would rapidly expand to occupy the whole box; and this would be true, however small the amount of gas and however immense the box, provided there were no disturbing forces like gravity. This fact about gases is sometimes expressed by saying that *gases tend to expand indefinitely;* by which is meant that they will so expand unless prevented by some external force.

Why do gases thus expand if left to themselves? This

has already been illustrated at page 72. By carefully reviewing the statement there made, you will see that it is a necessary consequence of the supposed continual heat vibration of the molecules of the gases.

As all gases with which we deal are under some compressive force greater or less than that of the atmosphere, they must all be constantly exerting an expansive or outward force or pressure. Of this we have familiar evidence in the explosive force of air or steam under great compression in air-guns and steam-boilers, as well as in the gases generated behind a cannon-ball by the burning powder, etc.

Absorption of Gases.—The reduction of the volume of gases may also be shown in an interesting way by the following experiment:

EXPERIMENT.—Fill with mercury a glass tube an inch in diameter and four or more inches long. Invert it in a vessel of mercury. Introduce into the tube over the mercury enough ammonia or carbonic acid gas to displace nearly all the mercury. Heat thoroughly a small piece of wood charcoal in the flame of a Bunsen or alcohol lamp (see page 230). Cool it by plunging it into the mercury, and then let it float up into the tube. The charcoal will soon absorb a large portion of the gas, and the mercury will rise in the tube. The gas appears in this case to be simply reduced in volume by a peculiar condensing action of the charcoal, and not to be chemically acted upon. It will be given off again by the charcoal upon heating. The preliminary heating was to expel gases already condensed within the charcoal.

Gases are also reduced in volume by solution in liquids. If water that has been standing in the air for a while be boiled, it may be found, with suitable apparatus, that a considerable volume of air which was held in solution is given off. If a tumblerful of cool water be drawn from the well or pipes and allowed to stand in a warm room for some time, bubbles of air will be found upon the inner surface of the glass. This is air held in solution by the cool water and given out by it as it becomes warmer. Fish breathe such air mechanically entangled in water. How? The foam and bubbling of soda and other mineral water is due to the giv-

ing off of carbon-dioxide (often but improperly called carbonic acid gas) held in solution under pressure.

QUESTIONS.—Describe the experiments showing the compressibility of gases. State the law of compressibility. Describe an experiment proving this law for pressures below one atmosphere; for pressures above one atmosphere. Why do we find it convenient to start with the atmospheric pressure rather than some other? Why is it necessary to confine gases on all sides in order to retain them? What would an unconfined gas not affected by gravitation do? What is meant by the statement that gases tend to expand indefinitely?

Are all gases with which we have to deal exerting an outward elastic pressure? How is this pressure explained on the molecular theory? Suppose a barometer-tube, with the mercury standing at 30 inches, be sealed up in a glass case full of air into and out of which no air can go. At what height will the mercury stand? The outside atmospheric pressure can not get at the cistern when thus sealed. Why, then, does not the mercury fall? What does this illustrate?

Describe experiments illustrating the expansive pressure of gases; an experiment showing the absorption of gases by solids. Are gases absorbed by liquids? How does absorption illustrate the compressibility of gases? Why is a boiler full of steam at 100 pounds pressure more dangerous—i. e., why does it possess more energy—than if filled with cold water under the same atmospheric pressure?

PUMPS AND SIPHONS.

The Air-Pump.—Fig. 11, on page 173, illustrates a simple form of air-pump. The use of this particular form is to remove air from apparatus for such experiments as many already described. The air-pump has, however, very important applications in commercial work, for removing air or other gases from apparatus of various kinds, such as the evaporating tanks in sugar-refining, the condensers of steam-engines, the globes of incandescent electric lamps, parts of ice-making machinery, etc. Air-pumps are of two classes—those whose parts are all solid, and those whose action depends on the use of mercury. The first kind only will be described here, and the common school air-pump will be selected as a type. Pumps of larger size, which are usually run by steam-power, are similar in principle.

Fig. 113 shows a vertical section of the pump illustrated on page 173. R is the receiver, N M the plate on which R stands, O the central tube passing through the plate and base to the pump proper, P'. S is a screw stop-cock. When turned forward, it closes the tube at its

point, so that no air can pass up into the receiver from the pump or outside. H is the handle of the pump, and moves the piston P′ in and out of the cylinder.

Start with S open and the piston down in the cylinder, as shown in the upper figure at P′, all being at rest. Then the valve at *b*′ is closed, and also the one at *a*′ in the piston, their weight keeping them down. The receiver, pipe, and pump, are full of air at the atmospheric pressure. Let H be pulled backward, moving in the direction of the arrow in the second figure. The space between the lower valve *b* and the piston P will thus be increased. The air will expand to fill this space, and will be thereby reduced in pressure. It will therefore press upon the front side of *b* less than the air in the receiver presses upon the rear side. Hence *b* will be pushed open into the position *b*″, and will be held open as long as H is moving outward. Thus all the air in the receiver, pipes, and pump below the piston, continues to expand as long as the piston moves. The valve *a* will be kept closed throughout by its weight and the atmospheric pressure outside.

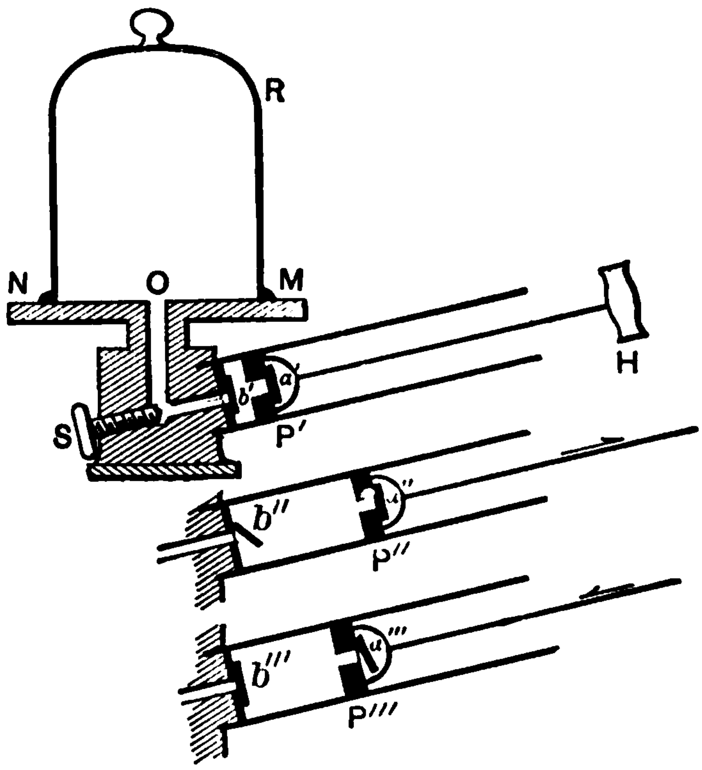


FIG. 113.—PRINCIPLE OF AIR-PUMP.

When P stops at the end of the stroke, *b*″ will fall into the closed position *b*′ or *b*‴ by its weight. The return stroke is made by pushing H inward as shown by the arrow in the lower figure. Valve *b* remains closed. Valve *a* remains closed also at first, until the air between *b*‴ and the piston P‴ is reduced to such a volume that its pressure is again equal to that of the atmosphere and just enough more to lift the weight of the valve *a*. Then, as the piston goes down farther, this air opens *a* into the position *a*‴, and continues to escape through it until the piston stops at the bottom of the cylinder, when, of course, *a* closes into its first position by its weight.

The operation is then repeated. As H is drawn out again, the air in the receiver opens *b* when the pressure of the air below P is reduced by its expansion to a little less than that in O, so that the weight of the valve can be lifted. The receiver air then holds *b* open and expands ...mp until the out-stroke is completed. Then *b* closes, the

in-stroke begins, *a* presently opens, more air passes out by the moving piston until the in-stroke is completed, and the operation begins anew.

Thus at each stroke a certain fraction of the air is removed. Suppose this fraction to be $\frac{1}{10}$. Then the first stroke removes $\frac{1}{10}$ of the air and $\frac{9}{10}$ remain. The second stroke removes $\frac{1}{10}$ of the remainder—i. e., $\frac{1}{10} \times \frac{9}{10} = \frac{9}{100}$ of the whole. There therefore remains $\frac{9}{10} - \frac{9}{100}$ or $\frac{81}{100}$ after the second stroke; $\frac{729}{1000}$, or say $\frac{73}{100}$, after the third, and so on. You will thus see that a smaller fraction of the original air is removed each time, and that we can never remove it all.

To obviate the difficulty of lifting the weight of the valves which interferes with very thorough exhaustion, automatic arrangements of various kinds are used in specially fine pumps.

The Lifting-Pump.—Perhaps the most familiar of the many forms of pumps is that used for raising water from wells, known as the lifting-pump. The glass model shown in the left-hand figure of apparatus numbered 12 (page 173), illustrates clearly its operation. The action of the pump will be described, however, with reference to Fig. 114, which shows an actual form of lifting-pump for water.

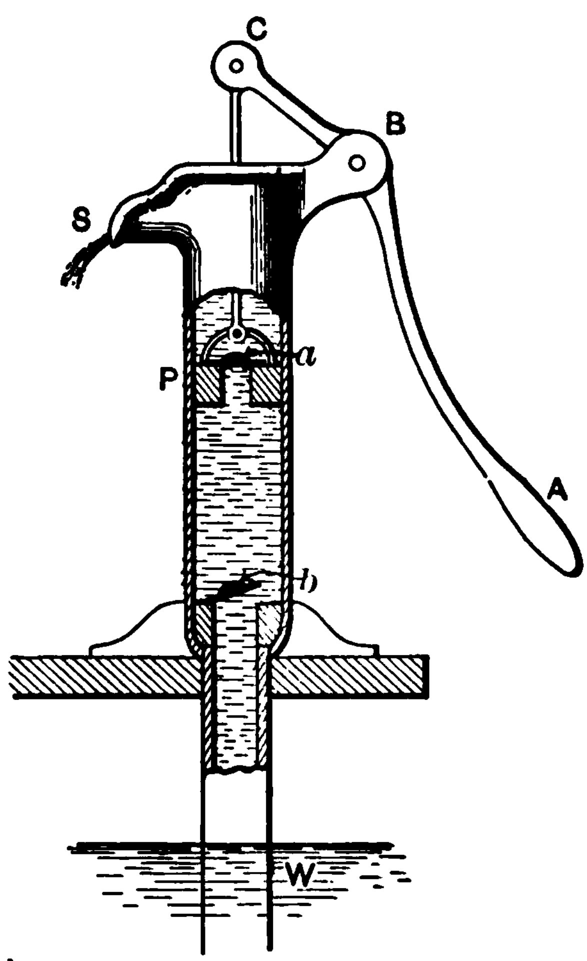


FIG. 114.—SECTION OF LIFTING-PUMP.

The valves of the lifting-pump work in precisely the same way as those described for the air-pump. Let us suppose the pump full of water and the handle A stationary. Then the upper valve *a* in the piston, and the lower valve *b* (fixed in position in the bottom of the pump), close of their own weight. The water can not then escape downward through them, as they and the piston are made water-tight. But why does the water stand up to *b* in the pipe above the surface of the supply W? Why does it not run down and leave the pipe empty—i. e., a vacuum? Why does the mercury stand at a height of 30 inches in the barometer-tube (Fig. 106)? Why does the water fill the inverted tube Fig. 105 and the

tumbler of the experiment on page 202? The water is kept up in the pipe by the atmospheric pressure when the pipe has once been filled, provided there is no leak. The atmosphere presses down on the water surface at W, and this pressure is transmitted through the water to the bottom of the pipe and up through the water in the pipe to the bottom of the valve. The valve *a* is then pressed upward on its under side by the atmospheric pressure less that due to the column of water whose vertical height is from *b* to the surface of W. It is pressed downward by the atmosphere plus the column above *b*.

Now, push down the handle A so as to cause C to rise, thereby raising P. Call this a forward stroke. As P rises, the water forced up by the atmosphere follows it, pressing open *b*, which is hinged at one side, and thus keeps the pump full up to the piston. The valve *a* is kept closed by its own weight and part of the atmospheric pressure. At the end of the forward stroke, P stops and *b* closes by its weight.

Then the return-stroke begins. As *b* is closed and kept so by its weight and by atmospheric pressure, the water above it can not escape. As P descends, therefore, the water beneath forces *a* open and escapes through it to the upper side of P. When the return-stroke is completed, P stops and *a* closes by its weight. A forward stroke is then begun and goes on as before, the water above P overflowing at S.

The amount of work done at each stroke in steady pumping is equal to the work required to lift vertically from W to S, against its weight, the mass of water which overflows; and in addition to do all the work of friction and acceleration. The actual mass of water overflowing is, of course, not lifted from W at that particular stroke; but the work done in lifting all the water in the pump the short distance through which it rises is equal to that which would be done in lifting the overflowing mass from W to S.

What is the source of energy which does this work? It is the source which acts on the handle A, whatever that source may be—e. g., a man or an engine. It is *not* the atmosphere or gravity. Without the atmosphere, the lifting-pump would not work, for the water would not stay up under the valve; but the atmosphere is not the source of the energy which does the work. The pump does just as much work against the atmosphere as the atmosphere does

upon the water in the pump—i. e., at each stroke, as much energy is restored to the atmosphere as is taken from it.

All the work (except a little friction) is done on the forward stroke. As this stroke is progressing, the upward pressure on the bottom of the piston is equal to the atmospheric pressure minus the pressure due to the column of water from P to W. The downward pressure on the top of the piston is that of the atmosphere plus that due to the column of water above P. The piston is therefore pressed downward on the whole by a pressure due to the column of water lifted. The force by which P must be pulled up is then equal to its *area* multiplied by the intensity of the pressure due to a water column of the height P W. The work done at each stroke is equal to this force multiplied by the distance through which P moves.

The action of the atmosphere may be regarded as simply holding the water up in the pump and pipe. Cohesion would do equally well if the water cohered, and also adhered to the piston with such force that its own weight would not pull it away.

How is the pump filled in the first place? If the piston and valves work air-tight, we may start with the pump empty—i. e., containing nothing but air down to the level of W. Then, on raising and lowering the piston, this air will be pumped out and the water will follow it up into the pump—that is, the pump will act as an air-pump until all the air is removed, and then it will be full of water and act as a water-pump. If the piston and valve do not work air-tight, some water is poured into the top of the pump. This serves temporarily to seal up the valves and piston so that they will not leak air, as water leaks through small crevices more slowly than air. The pump then works as an air-pump until the water fills it. If the pump leaks through the lower valve or at any point of the pipe below it, air will be drawn in and the water will run out when the pump is not in use. The pump is then said to be "run down." To prevent freezing, the water is often let out purposely by opening both valves or otherwise admitting air. The lower valve is usually provided with a point projecting upward and backward, so that when the piston is forced as far down as possible it presses upon this point in such a way as to hold both valves open.

The Limit of Height P W at which the pump can be placed above the level of the supply is about 34 feet, for the pump will not work above the height at which the water can be sustained by the atmospheric pressure. We have seen, on page 203, that this is 34 feet. In practice, however, the lifting-pump will often cease to work at a less height than this, as the atmospheric pressure will sometimes balance only about 30 feet of water. Of course, the greater the height P W, the larger the piston, and the smaller the pipe, the harder the pump works.

The pump-handle, as shown in Fig. 114, is a lever, and thus affords the mechanical advantage of using a small force through a long distance to do the work of lifting the piston through a short distance against a large force.

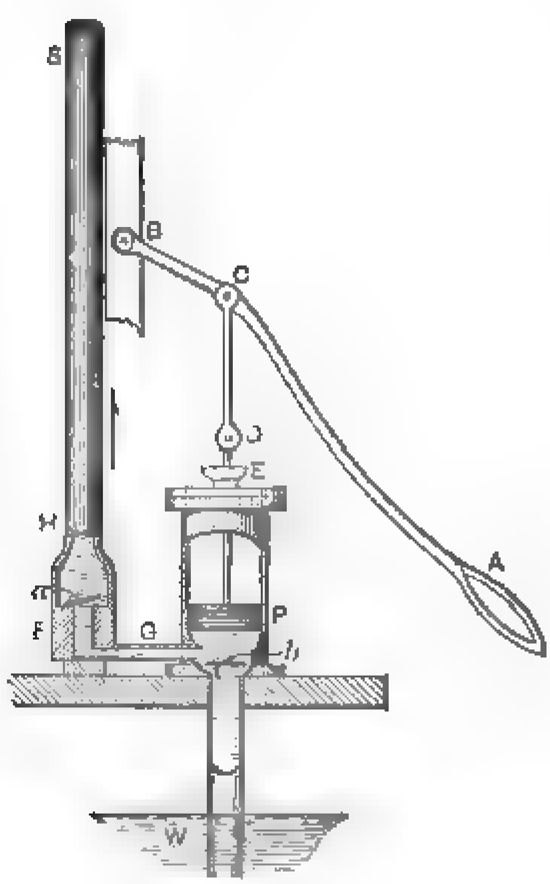


Fig. 115.—Section of Force-Pump.

The Force-Pump.—The glass apparatus illustrated in the left-hand figure of No. 12, page 173, clearly shows the action of the force-pump. Fig. 115 is a sketch of an actual pump. This kind of pump is used for forcing water upward, when it is desired to deliver the water at a point at which it is not convenient to locate the pump, when the water is to be raised above the limiting height of the lifting-pump, or when water is to be delivered under great pressure, as in fire-engines and other forms of pumping-engines.

The piston P is solid and is raised and lowered by the lever A C B through the connecting rod C D. Valves opening upward (usually hinged at one side) are placed at *a* and *b*. Assume the pump to be full of water in all the shaded parts. No water is supposed to go above the piston. Let an up stroke of the piston be started. The valve *a* will close by its weight and that of the water above it, and the water from the supply W will be forced up by the atmosphere through *b*, which will thus be held open. At the end of the up stroke, the valve *b* will close by its weight. At the beginning of the down stroke, the piston will force the water out ahead of it, and, as *b* is closed the tighter by this pressure, the water can escape only by opening *a* and passing through it into the delivery-pipe H S. This pipe leads off to the point at which it is desired that the water shall be delivered. It may be as high or as long as desired, the only effect of increased length and height being to require the application of more energy at A and greater strength of pump and pipes.

The Air-Dome, shown in Fig. 116, is usually connected with powerful force-pumps. Its object is to steady the pressure at which the water goes through the delivery-pipe.

Let A B be a section of some horizontal portion of the delivery-pipe H S near the pump. A branch pipe turns upward from A B, and upon this is placed the air-tight hollow dome of metal C D E. This dome is full of air. When the pump makes a down stroke, it forces water violently into the delivery-pipe, and would thus greatly increase the pressure and give a violent strain to all the piping. The dome reduces this shock, for, as the water is forced violently in at A, it finds the escape into the dome by compressing the air there easier than the violent passage out through B. The sudden rush of water passes partly into the dome, rising there from a level C to a higher one D and compressing the air. As soon as the down stroke ceases, the valve *a* closes and the compressed air in the dome forces the water out through B, lowering it to its former level at C.

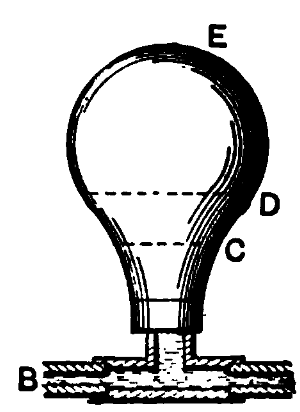


FIG. 116.—AIR-DOME.

This operation goes on at each double stroke. Thus the air-dome relieves the violence of the shock in the pipes beyond it, and to some extent also in the pump and the connecting pipes. It also makes the rate of delivery more uniform, as owing to its action there will be water flowing through B during the up stroke when there would be none

without it. This dome may be seen on steam fire-engines, and on almost all "power pumps"—i. e., pumps run by steam-power.

The Siphon.—Bend a glass tube, one or two feet long and a quarter of an inch in diameter, as shown at A B C, Fig. 117. Leaving it full of air, dip one end into a vessel of water D and let the other hang out into the air or dip into another dish of water at E. No action will take place. Now take the tube out and fill it with water. Close each end with a finger and dip one into D, the other into E. Water will flow through the tube, from the vessel D in which the water surface is at the higher level, into E, in which it is at the lower level.

Make the level of the surfaces in D and E the same. The flow will cease. Leave the end C free in air. The water will flow freely out of it, gradually emptying D. Pull the tube up until A is out of water, or let the action go on until the water is drawn down to A. Air will enter, filling the tube, and the action will cease. Any tube acting in this way is called a Siphon. A glass tube has been used in the experiment merely because it enables the operation to be more clearly seen. A tube of rubber or metal, or any other material, will give the same results.

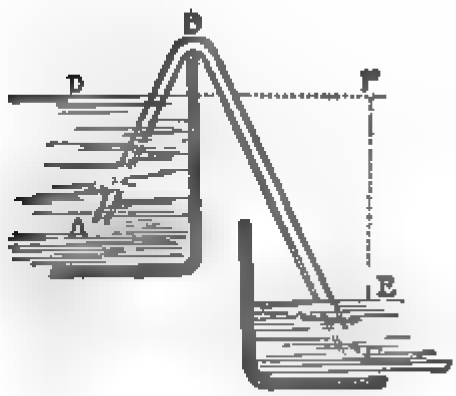


FIG. 117.—SIPHONING.

Why does the water flow? In the first place, suppose the level of the water in D and E to be the same, and hence no flow to be taking place. The water still fills both sides of the tube up to B. It is retained there by the atmospheric pressure on D and E, and the tube will thus be kept full when once filled, however long either arm, within the limit of 34 feet. Next suppose one surface, E, to be lower than the other, D. Then at the top section B, the pull on the water toward E is that due to the column of water whose height is the vertical distance from B to E, while the pull toward D is that due to the differ-

ence of level B D. There is, therefore, a resultant pull toward the lower level of an amount proportional to the difference of these two heights, which is F E, the difference of level of the two surfaces. The water will therefore flow from D to E as fast as this force can draw it against the resistance due to friction in the pipe, etc.

The siphon requires the atmospheric pressure merely to keep the water together in the tube. If the water had cohesion enough to hold itself together, the siphon would work without the atmosphere. In fact, a short siphon will work under the receiver of an air-pump.

The Source of Energy that works the Siphon is gravity, the force being the weight of the liquid. The moving liquid acquires no energy from the atmosphere. As the working force is proportional to the difference of level of the surfaces of the supplying and the receiving liquid, it is evident that the greater this difference of level the faster the siphon will work, other things being equal. The larger the tube, the less the friction and the faster the flow; but if the tube be very large and the flow slow, air may bubble up into the siphon and stop its action.

The siphon is of service in causing a flow of liquid from one place to another when a pump is not available; in emptying a vessel in which it is desired not to bore a hole at the bottom; in transferring acids which it is inconvenient or dangerous to handle, etc. The form of tube used may be anything that is convenient for the purpose at hand; the difference of level is the thing essential to its working.

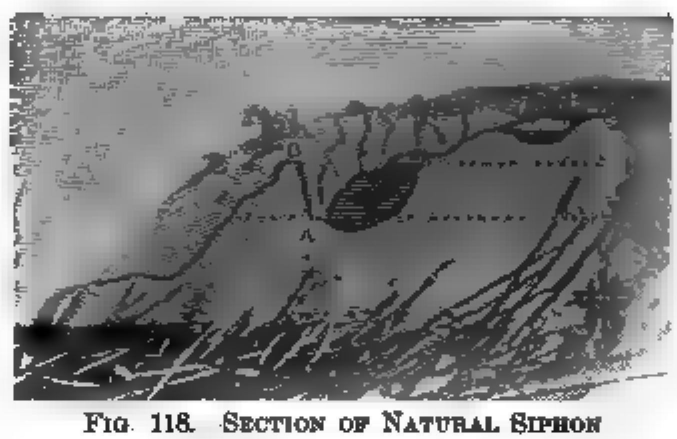


FIG. 118. SECTION OF NATURAL SIPHON

Crevices in rocks sometimes act as siphons and drain underground cavities, giving rise to intermittent springs. In the section shown in Fig. 118, the water derived from surface drainage will rise to the level B L in the reservoir before the crevice begins to discharge it at A. Why? The crevice will continue to drain the cavity until the level is reduced to A L, when the flow ceases. Why?

QUESTIONS.—Describe the action of the Air-Pump. Would the air-pump work if gases were not self-expansible? Can all the air be removed from a vessel by a perfect air-pump? Why? Describe the construction of the Lifting-pump, its mode and principle of action. Would the pump work if the atmospheric pressure were removed? What part does the pressure play? Where does the energy come from which lifts the water? How much energy must be supplied at each stroke? Would you think it correct to say that in raising the piston of the pump the atmospheric pressure was partly or wholly removed by that means from the top of the water column and the atmosphere thus permitted to force up the water beneath the piston? If so, show that the work done upon the atmosphere in that operation is equal to that done by it. If we had a liquid endowed with strong cohesion and adhesion, could it be pumped *in vacuo*? May we then say that the atmospheric pressure supplies the place of cohesion in the action of the pump? What is the average highest limit at which a lifting-pump can be worked above the supply?

Describe the form and action of the Force-Pump. Show how it is only a slight modification of the lifting-pump. Take the case of a well in which the water stands 50 feet below the surface, and suggest some way of pumping the water out. Describe the action of the Air-Dome.

What is a Siphon? Describe its action. Will it work *in vacuo*? To what extent? Why does it depend upon the atmosphere? What is the source of energy which transfers the water? The water at the lower level has less potential energy than at the higher, and after it has become still it has no energy of onward motion; what, then, has become of the energy expended upon it in the siphon? Would the water be warmer after passing through the siphon? Should you expect to detect the difference with the sense of touch? Why? Some miners desire to empty a large wooden water-tank, but do not wish to bore a hole in it, and have no pump; they are at a loss to know how to proceed. What method can you suggest? Explain intermittent springs. Ascertain what the Tantalus Cup is, and explain its action.

DIFFUSION OF GASES.

Diffusion through a Porous Partition.—In Fig. 119, B represents a porous earthenware jar, such as is used in some electric batteries. It is inverted, and its open end is plugged with a rubber or cork stopper, through which passes a glass tube, C, opening into the jar and dipping into a colored liquid in D. A large glass jar or wide-mouthed bottle, A, can be held inverted, as shown, over B. Let A be removed and held over a hydrogen generator or jet of illuminating gas. The hydrogen will rise and fill A. Then let A be carefully pushed down over B, as in the figure. Bubbles of gas will at once begin to come up through the liquid in D, showing that the amount and pressure of the

air within B has been increased, and that gas is accordingly forced out through the tube.

What has taken place? The hydrogen from A must have passed through the pores of B into the interior. It does so by a process called Diffusion, which is of the same character as the diffusion of liquids described on page 179. But not only has the hydrogen gas diffused through the pores of the jar into its interior, but some of the air from within has diffused outward at the same time. The hydrogen, however, goes in faster than the air comes out. When B was standing in the air before the experiment, diffusion of the outside air into the interior, and of the inside air outward, was similarly taking place. We did not observe it, because the diffusion each way was at the same rate, the gas being the same, and at the same temperature, inside and out. Thus hydrogen and air diffuse at different rates.

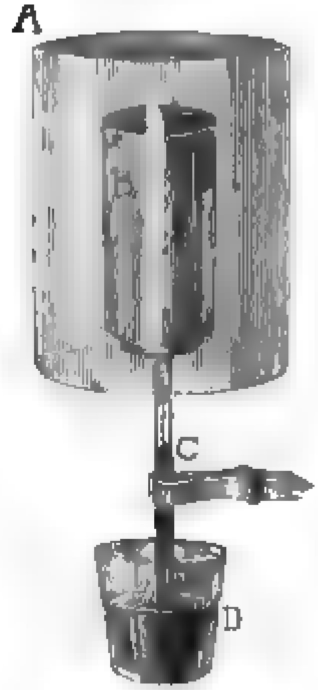


FIG. 119.

EXPERIMENTS.—Remove the jar A immediately after the experiment above. The liquid of D will rise in the tube, for there is now only air outside B, while inside there is a mixture of hydrogen with air. This mixture diffuses outward faster than the air diffuses inward.

After all the hydrogen has escaped from B, fill A with carbonic-acid gas. This is heavier than air, and will escape when A is inverted, unless the mouth of the jar is kept closed with a cardboard. Invert A over B. The liquid will now be seen to rise in C. The carbonic-acid gas diffuses more slowly than air.

Gases are thus shown to diffuse through porous partitions. In general, the less dense gases—e. g., hydrogen—diffuse faster than the more dense ones, as carbonic acid.

Free Diffusion.—Gases also diffuse into each other when merely in contact, and not separated by porous par-

titions; this can not be as conveniently shown experimentally, but may in a measure be illustrated thus:

Pour a little strong ammonia-water into a shallow dish in a small closed room. A smell of ammonia will soon be perceived throughout the apartment. This illustrates the free diffusion of gases, as ammonia is a gas, ammonia-water being a solution of this gas in water. When the solution stands open, some of the gas passes off into the air and quickly diffuses through the room. Most odors are gases or vapors diffusing in this way.

The diffusion of one gas into another is similar in nature to liquid diffusion. The molecules of each gas, in their free movement, pass off into the spaces between the molecules of the other gas. Why do the less dense gases diffuse faster? Equal volumes of all gases contain the same or nearly the same number of molecules. Hence the molecules of the less dense gases have the less mass. At the same temperature, the less massive molecules move faster than the more massive ones, and therefore penetrate farther in the same time.

Diffusion through Membranes.—Fill a small bottle having a large mouth with hydrogen, and tie over it a piece of softened bladder. The bladder will at once begin to be drawn, or rather pressed, inward in a concave form. The hydrogen diffuses outward faster than the air passes in, leaving a partial vacuum.

Fill the bottle with carbonic-acid gas instead of hydrogen. Fill a larger inverted bottle with hydrogen and hold it down over the bottle of carbonic acid. The bladder will bulge outward, for the hydrogen diffuses inward faster than the carbonic acid outward, thus making the pressure inside greater than that outside.

These experiments show that gases possess, like liquids, the property of Osmosis, or diffusion through membranes.

THE EARTH'S ATMOSPHERE.

The Atmosphere consists of an immense mass of invisible elastic fluid, which we call *air*, completely surrounding

the earth, and held in place by its own weight. It consists chiefly of four volumes of nitrogen and one of oxygen, but also contains less than one per cent of vapor of water and a small amount of carbonic acid. Owing to free diffusion and to the stirring action of winds, the atmosphere is a thorough mixture of these gases, the proportions, except of aqueous vapor, being everywhere almost exactly the same, except in confined spaces, such as buildings, mines, etc.

As this atmosphere is kept in place by its weight only, the pressure within it must be greater the farther we descend into it from the outside, just as the pressure increases with the depth in a liquid. Indeed, the atmosphere has been likened to an ocean of air. But air is easily compressible, and, of course, the more it is under compression the more dense it is. Therefore, if we were to descend from the outside into the earth's atmosphere, we should find not merely that the pressure was greater, but that the air was more and more dense the farther we descended. Thus, while the water pressure, as we descend into the ocean, would be found to increase proportionally to the depth, and the water to be of sensibly uniform density, owing to its very slight compressibilty—in descending into the earth's atmosphere, we should find the pressure to increase much more rapidly than in proportion to the depth, and the density of the easily compressible air to increase more rapidly also. In other words, if we were to ascend from the surface of the earth, we should find the air growing less dense (or more rarefied), and the pressure lessening more rapidly than in proportion to the height. Owing to this fact, the greater part of the mass of the atmosphere is near the earth, one half of it being probably within three and a half miles of the earth's surface. The upper air is extremely rarefied, and shades off, as it were, very gradually into empty space.

The Depth of the Atmosphere, or the distance to what may be called its upper limit, can not be accurately

determined, for this limit is not well marked; but it is estimated to be between thirty and sixty miles. It is probable that there are minute perceptible traces of air as high as several hundred miles from the surface. If the atmosphere

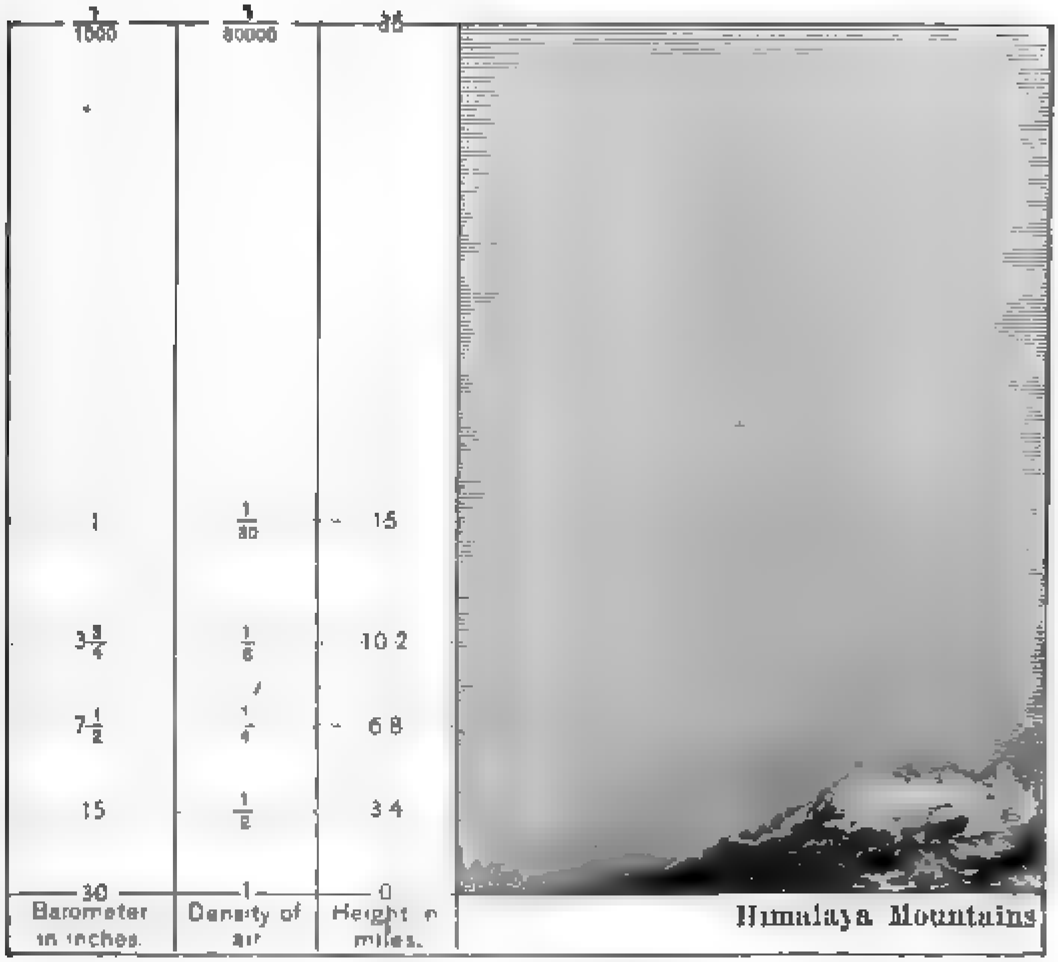


FIG. 120.—DIMINUTION IN DENSITY AND PRESSURE OF AIR WITH INCREASE OF HEIGHT

were of uniform density throughout, the same as that at sea-level, it would be sufficient in volume to cover the earth with a layer only about five miles deep, out of which some of the highest mountains would project.

The atmosphere, or more properly the air, does not stop at the earth's surface, but penetrates into all holes, crevices, and porous substances, and must therefore be present at considerable depths. Its density at such depths may become very great.

The Atmosphere exerts the Pressure due to its Weight upon all objects on the earth, our bodies included.

The total force thus exerted is enormous, although we do not perceive it.

For example, the surface of a man's body is about 16 square feet, or 16 × 144 = 2,124 square inches. The intensity of the atmospheric pressure is 14·7 pounds per square inch. The total pressure on the surface of the body is, then, 2,124 × 14·7 = 31,200 pounds, or nearly 16 tons. It might, at first thought, seem that this pressure must crush us. It would do so, were it applied merely upon the outside; but, through the air and liquids contained in the tissues and passages of the body, this pressure is rendered the same in all directions throughout the interior of the body.

The Measurement of Heights by the Barometer depends upon the vertical diminution of the atmospheric pressure. If a barometer be read at the foot of a mountain and then at the summit, the second reading will be less than the first. From the difference in reading, the law of diminution being known, the height can be computed.

Owing to the disturbances of pressure accompanying storms, and to irregularities due to temperature and humidity, barometric indications do not afford an exact method of measuring heights. The barometer falls about one inch for the first one thousand feet above sea-level, but this rate is not maintained.

Buoyancy of Air.—Fig. 121 shows a hollow sphere suspended from one arm of a balance beneath the receiver of an air-pump. Any light object will answer instead of the sphere. With the receiver removed, adjust the weight on the balance-arm until the sphere is exactly counterpoised. Then put the receiver in place and exhaust the air. The sphere will descend, showing that its weight has apparently increased as compared with that on the other arm of the balance. But no change has been made except the removal of the air from the receiver.

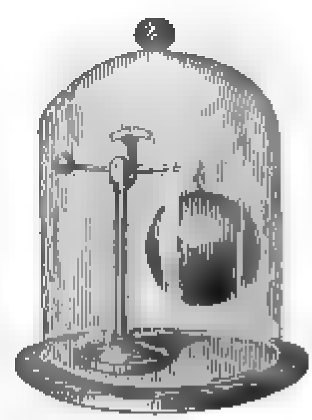


Fig. 121. Globe under Receiver.

Why has the sphere appeared to gain weight? We have seen that any body immersed in water appears to lose weight, or is buoyed up, by

an amount equal to the weight of water displaced. Objects in air, and in all fluids, are buoyed up in precisely the same way by an amount equal to the weight displaced. Thus, when the sphere was counterpoised in the air, it was buoyed up by the weight of its volume of air. All the other parts of the apparatus were also similarly buoyed up. When the air was removed from around the apparatus, the buoyancy ceased. Every part of the apparatus gained in apparent weight, then, by an amount equal to the weight of the air it had displaced. But the sphere, being larger than the other parts, displaced more air, and therefore was more buoyed up. Hence, when the buoyancy was removed, it appeared to gain more in weight than the other parts, and that side of the balance went down.

In weighing any object accurately, the buoyancy of the air must be allowed for. Both the object and the weights are, of course, buoyed up, and appear too light. But generally the weights are of brass, which is more dense than most materials, so that the object loses more in weight than the weights. The weight of a litre of air is only about one gramme, so that the loss of weight of most objects is so small as to be neglected in commercial and in most engineering work. As all objects everywhere about us are buoyed up, and as we never go outside of the air, we do not ordinarily notice this buoyancy.

FIG. 122.—HYDROGEN BUBBLES, ILLUSTRATING PRINCIPLE OF BALLOON.

The Balloon.—The effect of the buoyancy of the atmosphere is easily perceived in its action on bodies of less density than air.

Fig. 122 represents bubbles blown by hydrogen gas issuing from a hydrogen generator. Instead of hydrogen, ordinary illuminating gas will answer equally well, a glass tube or a clay pipe being connected with the gas-jet by a rubber tube, and its end dipped into the soap mixture of page 174. The hydrogen is so much less dense than air, that the bubble, even including the weight of the film and hydrogen together, is lighter than the air displaced.

It is therefore buoyed up by a force greater than its own weight, and, like a block of wood in water, tends to rise.

The hydrogen bubble is a miniature Balloon, for a real balloon is merely a bubble whose walls are of a very light, strong material, such as silk made impervious to hydrogen. The balloon is filled or inflated with this "gas," and therefore rises with the car and its load. The large size of an ordinary balloon is requisite in order that the difference in weight between the hydrogen contained and the air displaced shall be at least equal to the weight of its walls, together with that of the car and its contents. The ordinary toy-balloon is a rubber bag inflated with hydrogen or illuminating gas. The gas soon escapes by diffusion through the rubber, allowing the bag to collapse.

On account of the buoyancy of air, hydrogen and other gases less dense than air tend to rise through it. Hydrogen, for instance, can be held in a jar placed mouth downward, while it would rise quickly out of a jar placed mouth upward. It can be poured from one jar into another by holding them both mouth downward and then inclining the one containing the gas beneath the mouth of the other, into which the hydrogen will rise, displacing the air. This process is exactly the opposite of pouring water, as it is pouring upward instead of downward; but gravity is in each case the source of energy.

Gases more dense than air can be poured just as water is. Hot air, being less dense than cold air, is buoyed up in cool air by a force greater than its weight, and therefore tends to rise. This gives us the draught in our chimneys as well as many of the currents of the atmosphere. Smoke is mainly composed of particles of carbon which rise only because carried along by hot air. Hot air was also used instead of hydrogen in the earliest forms of balloons, and is the means by which fire-balloons are made to rise.

QUESTIONS.—Describe an experiment to show the diffusion of gases through a porous partition. Give an account of the free diffusion of gases. How is it explained on the molecular theory? Which diffuse faster, the more or the less dense gases? Why? Illustrate the osmosis of gases.

Of what does the atmosphere consist? Draw a diagram illustrating the variation of pressure of the atmosphere with the height? If a barometer were carried up to a point where it read only 15 instead of 30 inches, how much of the mass of the atmosphere would be above it? About how high would this be? What

is said of the height of the atmosphere? Why do not the gases of the atmosphere stratify, as oil and water do, into layers of nitrogen, oxygen, etc.

A house is 30 feet long, 40 feet broad, and 30 feet high, with flat roof. How much is the total atmospheric pressure on its outside surface? Why does it not collapse? Would it collapse if the air were removed from it?

Why do we suppose that air exerts a buoyancy? How may we prove it? How is this allowed for in weighing? Why is it imperceptible in ordinary weighing? Why do bubbles filled with hydrogen rise? Why does hot air go up the chimney? Does it appear to you that gases and liquids closely resemble each other in properties? More closely than liquids resemble solids?

MISCELLANEOUS QUESTIONS AND PROBLEMS.

State the principal distinction between gases and liquids.

If one end of a skein of silk be placed in a tumbler of water and the other be allowed to hang over the side, why will the tumbler in time be emptied?

Why, in an ordinary well, does not the water rise to the earth's surface?

Did you ever see locks on a canal? If so, explain by diagram the principle on which they are operated.

Is the city or town in which you live supplied with water from some pond or lake? How far is the water conveyed in pipes? How high does it rise in the dwelling-houses? Explain the principle of the garden fountain.

Bore a hole in the bottom of a pail of water. What happens? Bore a hole in the side of the same pail. What takes place? Bore a hole in the bottom of an empty pail and hold it upright in the water. What occurs? What do these three results prove?

Why does water run into a leaky boat?

A box 4 feet deep by 2 feet wide by 3 feet long, with its bottom horizontal, is full of water. What is the intensity of pressure on the bottom? What is the total pressure on the bottom? What is the average intensity of pressure on its side? What the total pressure? What is the total pressure on the end? What would be the weight of water contained in the box? If the box was closed on the top and a square tube 12 feet high and 0·1 inch on a side projected vertically from it and was full of water, what would be each of these pressures? What would be the total weight of the water? How is it possible that the pressure on the bottom of the box can be so much greater in the second than in the first case with so little more water? Where is the upward pressure exerted in the second case which counterbalances all the downward pressure except that exerted through the lower end of the tube? What would be the amount of each of these weights and pressures if mercury were used instead of water?

Will a minnow-bucket even-full of water weigh more if a dozen live minnows are placed in it? Why?

How many cubic feet of cork would be required to make a life-preserver capable of supporting a person of 150 pounds weight?

Can you draw a diagram explanatory of the principle of the pneumatic inkstand?

Why can you float better in salt water than in fresh? In a lake like Great Salt Lake than in the ocean? Can you think of any way in which you can increase your buoyancy in water? Why is it dangerous to struggle and raise the arms if you fall into the water and can not swim? What should be done under such circumstances?

Wild ducks and geese, whose breasts are covered with thick down, float easily on water. Think of a reason.

Why does a loaded vessel, in ascending the Mississippi from the Gulf, draw more and more water as she proceeds ?

Dip the corner of a piece of blotting-paper into your ink-stand and explain what takes place.

Did you ever notice in raising a filled bucket from a well that it becomes heavier the moment it leaves the water ? Why is this ?

In the common atomizer used for spraying the throat, why does squeezing the rubber-bulb force into the air fine drops of the solution contained in the bottle ? Explain the double action.

How high does water rise in a boat's " well " ?

Why does the body of a drowned person sink, but after a few days, if the water is comparatively shallow, rise to the surface ? *When water is breathed into the lungs, the specific gravity of the body is increased and causes it to sink. After remaining under water for a time, light gases are generated within the body, distending it, and thus lessening its specific gravity, so that it floats.* Can a lake be so deep that the body of a person drowned in it will not rise ?

The centrifugal tendency in the gyratory motion of a tornado is tremendous, and the diminution of atmospheric pressure at the center is such as to create a partial vacuum. Explain then why, when a tornado passes over a building, the structure may burst into fragments.

It is desired to know whether a supposed silver piece is pure. Its weight in air is found to be 16·8 grammes, in water 14·8 grammes. Is it probably silver ?

A bottle empty weighs 35 grammes ; full of water, 65 grammes ; full of another liquid, 75·8 grammes. What is the density of the liquid ? What is the liquid ?

Into what space must we compress 10 cubic inches of air to double its elastic force ?

What is the weight of 600 cubic inches of air ? What is the weight of the same bulk of water ?

A vessel full of air weighs 1,061 grains ; exhausted, it weighs but 1,000 grains. How many cubic inches does it contain ?

What amount of atmospheric pressure is supported by a boy whose body contains 1,000 square inches of surface ?

When the mercury in the barometer stands at 29 inches, at what height will a column of water be supported by the atmosphere ?

When the atmosphere supports a column of water 32 feet high, how high a column of mercury will it support ?

How far above the earth's surface would the mercury stand only two inches high in the barometer ?

Does the air stop at the earth's surface ? What must be its density in deep mines ?

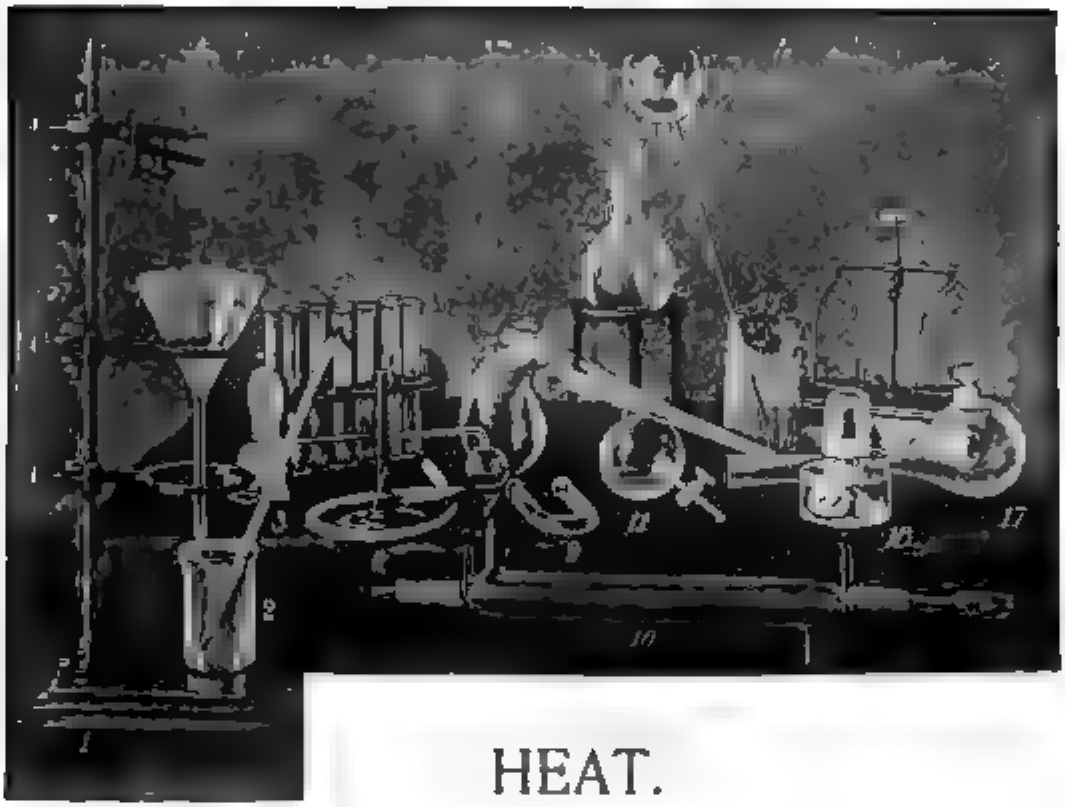
How many cubic feet of air would it take to weigh as much as 4 cubic feet of water ? *Ans.* 3,333$\frac{1}{3}$ *cubic feet.*

How much would a cubic foot of gold weigh ? How much, one of silver ?

What would be the weight of 4 cubic feet of marble ?

Suppose a room 10 feet high, long, and wide, to be filled with gold, what would the gold weigh ? *Ans.* 1,212,500 *pounds.*

If a balloon with car loaded weighs 500 pounds, how big must it be, if filled with hydrogen, just to carry this load ?



HEAT.

NATURE OF HEAT.

Heat is a Form of Energy possessed by bodies in virtue of an irregular motion of their molecules, as described on page 37. It addresses the sense of touch. Its nature is imperfectly understood. We consciously perceive it when it is communicated from anything hot to our persons, but we can not explain what it is.

Heat neither increases nor diminishes the weight of bodies. An iron ball when cold is exactly as heavy as it is when heated red-hot.

NOTE.—With the simple apparatus shown above most of the experiments described in the following section on Heat may be performed: No. 1 represents an iron support, with sliding rings; 2, a glass beaker; 3, a cylindrical bulb thermometer; 4, a glass funnel; 5, a test-tube stand with tubes; 6, a Bunsen burner, with regulator for the air, intended to be connected with a gas-jet by a length of rubber tubing; 7, a pulse glass; 8, a glass retort; 9, a U-shaped tube; 10, a condenser; 11, a glass balloon, with stop-cock, for weighing gases; 12, a metal tripod; 13, a glass flask; 14, a glass air-thermometer; 15, an aspirator bottle for siphon; 16, a standard balance; 17, a retort receiver; 18, a spirit-lamp, which must be substituted for the Bunsen burner when illuminating gas is not accessible. A few perforated rubber corks of different sizes should also be procured, a

When heat is communicated to a body, the body is not necessarily perceptibly warmed. If heat be communicated to a substance and does not perceptibly warm it (as when a tumbler of hot water is poured into a pitcher of broken ice), such heat is said to have been "rendered Latent"—in reality, it has been changed into other forms of energy, sometimes partly, sometimes wholly, outside the substance in question.

Temperature.—When a body feels hot or cold, we may express the fact by saying that its Temperature is higher or lower than that of the hand. We can not always judge correctly of the temperature of a body by our sense of touch. If, for instance, an iron rod and a piece of wood be exposed for several hours in a hot oven, the iron will feel much hotter than the wood. The iron may even blister the hand, while the wood can be held without inconvenience.

Similarly, in arctic regions, very cold iron will blister, so that the iron-work of vessels is covered with badly conducting material (see page 276) to prevent the cold metal from coming in contact with the hand. Wood and cloth at the same low temperature do not feel cold. This is because the hot iron parts with its heat more readily than the wood or cloth, while the cold iron removes the heat more rapdily from the hand. A similar fact is observed in the case of oil-cloth and carpets at the same temperature.

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glass stirring rod, some rubber tubing, and a pound of assorted glass tubing, which may be cut with a wet three-cornered file, or softened in the alcohol or Bunsen flame, and drawn into any desired shape. It is advisable always to protect a glass retort from the Bunsen flame by a square of fine wire gauze. The teacher or pupil will be supplied with this outfit, at a moderate price, by any manufacturer of philosophical apparatus. Where economy is necessary, a sufficiently accurate balance may be made with a cross-bar of hard wood and scale-pans cut out of tin. A glass bottle divided in halves furnishes at once a beaker B and a funnel F. Prof. Woodhull, in his "Home-Made Apparatus," suggests that a deep incision be filed in the side of the bottle, and a hot poker be drawn from the incision round the bottle in the required direction. A crack will start at the incision, and follow the poker till the bottle is divided. If a piece of yarn saturated with kerosene be wound twice round a common beer-bottle and lighted, and the whole be then plunged into cold water, the bottle will separate as shown in the cut. Holes may also be bored in glass vessels by means of a broken-off round file, and glass tubes fitted therein with the aid of rubber corks or tubing.

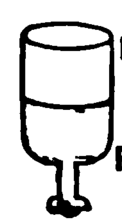


FIG. 124.

EFFECTS OF HEAT.

When Heat is applied to a Body, the effect produced varies with the nature of the body. Heat may cause a rise of temperature, or, as we ordinarily say, the body may become warmer. If the body is solid, it may fuse or liquefy when heat is applied; and liquids may be vaporized by a continued addition of heat. Some bodies, like wood, do not fuse, but decompose into constituent compounds or elements; others, like paraffine, decompose after fusion, but before vaporization proper sets in. Heating a body also causes a change in its volume. In most cases, bodies expand when heated.

Conversely, if heat be removed from bodies, the changes above named generally take place in the reverse order. Vapors condense into liquids, liquids solidify, and the temperature of bodies falls. If heating a body causes it to expand, cooling will cause it to contract, and *vice versa.* But the decomposition of bodies effected by heat is not capable of being reversed by a simple process of cooling.

Rise of Temperature produced by Heat.—If a vessel of iced water be placed upon a stove, the water becomes warmer, and soon begins to boil. During this operation, the heat obtained at the expense of the burning fuel is being continuously added to the vessel of water. The vessel may be removed to a cold room, where it will serve as a source of heat; for, as it cools, it imparts the heat which it has received to the room. One system of heating buildings is by the cooling of hot water conveyed in pipes.

If the vessel be placed in an ice-box, where it is entirely surrounded by ice, it will cool down to the temperature of the ice. During this operation, the hot water parts with heat, which melts a portion of the ice. The vessel of cold water might now be used to cool a hot room, just as the hot vessel was used as a source of heat. This principle is applied to the cooling of railroad cars, etc., in hot countries.

During the coldest mornings in winter, a piece of ice lying on the ground may be much colder than another piece which has just formed by solidification. If heat be applied to the former, it will not at once fuse, but will first become warmer; and this operation, like those previously described, will require time. The ice behaves like lead or iron which have cooled below the temperatures at which they fuse. The difference in these cases is that lead must be made much warmer than ice, and iron still warmer than lead, before fusion will take place.

Expansion of Solid Bodies by Heat.—The expansion of a solid may be illustrated by means of an apparatus like that shown in Fig. 125.

Provide yourself with an iron ball or grape-shot, to which a blacksmith will attach a metal hook, so that you can manage it when hot. Then have constructed an iron ring just large enough to let the ball pass through when they have the same temperature. If the ball alone is heated in the flame of a spirit-lamp or Bunsen burner, it will expand

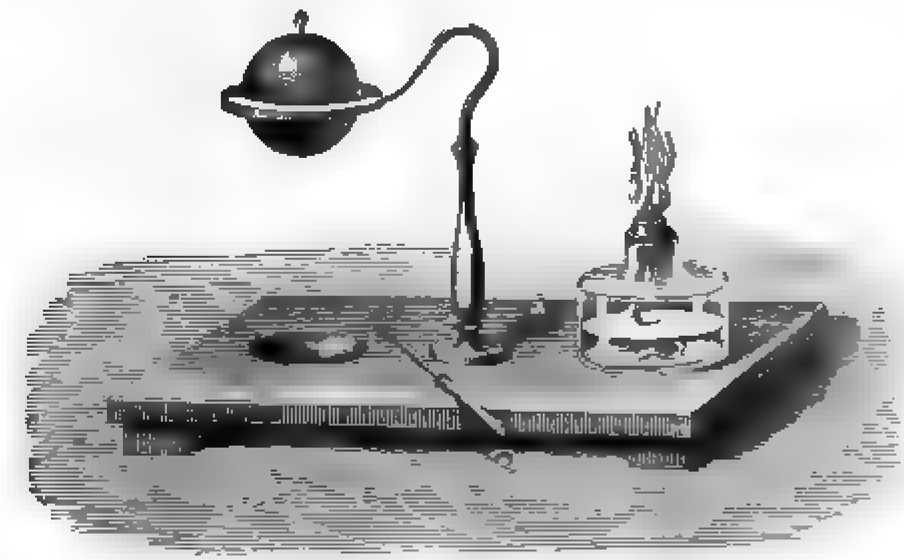


FIG. 125.—EXPANSION ILLUSTRATED.

to such a degree that it can not pass through the ring. If the ring alone is heated, it will be too large to fit the ball closely, and the ball can be made to rattle against its interior rim. If both are heated or cooled alike, the ball will always fit the rim. On this principle, the blacksmith heats the iron tire before applying it to the wooden wheel.

If a bar of metal is heated, it elongates. In a railroad track, the rails are always left with a little space between their ends, in order to allow for expansion. Conversely,

when iron cools, it contracts. The tie-rods of bridges expand and contract under the influence of extreme heat and cold, sometimes to such an extent as to endanger the structures.

Expansion of Liquids and Gases.—To illustrate the expansion of liquids, secure a large glass bulb with a capillary stem (see Fig. 126). Insert the open end of the stem in water, and warm the bulb by the hand or with hot water. The air will expand, and part of it will be expelled. As the bulb cools, the air within will contract, and some water will enter through the capillary stem. The bulb may then be placed in an upright position, and the water within boiled, care being taken to keep the whole interior of the bulb wet, in order to prevent breakage. If the bulb be again inverted and the end of the stem plunged under water, the bulb will gradually fill as it cools. Why? In filling a bulb with alcohol or ether, the source of heat should be hot water, and not a flame, in order to avoid explosions.

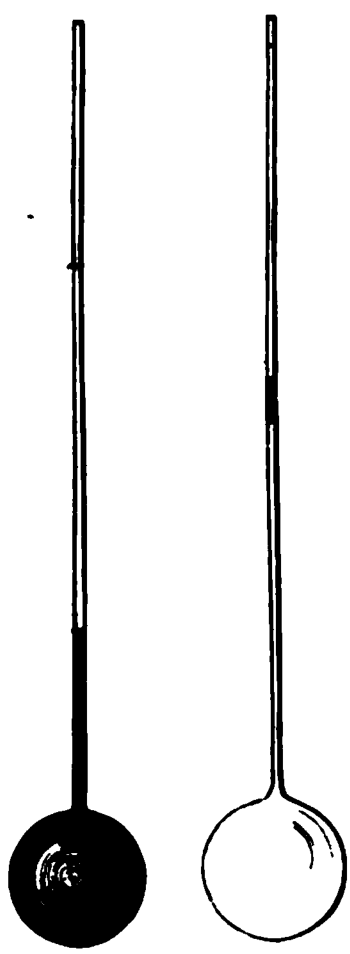


FIG. 126.—BULB-TUBES.

By repetitions of the operation just described, the bulb and a portion of the stem are filled with liquid (see Fig. 126). If the bulb be now placed in hot water, or in melting snow or ice, the expansion or contraction of the liquid within will be indicated by its rise or fall in the tube. The amount of this rise or fall will be greater, as the volume of the bulb is greater, or the bore of the tube is less. Doubling the volume of the bulb will make the rise twice as great, although a longer time will be required to heat the bulb throughout. Reducing the bore of the tube one half will also make the rise twice as great, without increasing the time required by the bulb to respond to a change in temperature.

The Expansion of Air may be illustrated with the same apparatus by introducing into the stem a small globule

of mercury as an index, the bulb being filled with air. The heat of the hand is sufficient to send the index through the entire length of the tube, which should be in a horizontal position. Such bulb-tubes are called Thermoscopes.

QUESTIONS.—What is Heat? Outline the accepted theory. When heat has been communicated to a body and does not perceptibly warm it, what has taken place? Illustrate your answer. What is such heat sometimes called? Which of the senses does heat address? How does heat affect the weight of bodies?

What is the Temperature of a body? Can we judge of a body's temperature by the sensation it produces when we touch it? Advance facts to prove your answer. What phenomena are observed in arctic regions?

State the several effects of heat; of cold. Explain the principle on which the heat of burning fuel causes a rise of temperature in water; the principle on which heat applied to ice may not at once melt it. Show that metals fuse in accordance with the same law. Can you suggest an experiment by which the expansion of solids by heat may be illustrated? Experiments showing the expansion of liquids and gases? What is indicated by the Thermoscope?

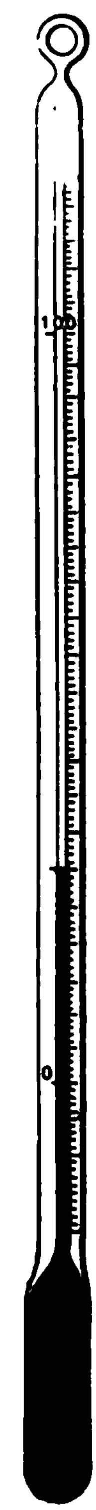


FIG. 127.—CYLINDRICAL BULB THERMOMETER.

THERMOMETERS AND THERMOMETER-SCALES.

The Thermometer, as usually constructed, consists of a spherical or cylindrical glass bulb, provided with a stem having a fine capillary tube. The bulb and a part of the stem are filled with some liquid, which is then boiled to expel all the air, and the tube is sealed up. Thermometers intended to be used at very low temperatures are usually filled with alcohol, while those designed for ordinary or higher temperatures contain mercury. The air thermometer, already described, is still used. It was employed to measure differences in temperature as early as the sixteenth century, Galileo's first thermometer being constructed on this principle.

Thermometer-Scales.—The scale of the thermometer is established by inserting the

bulb in melting ice, and in steam from water boiling under the average pressure of the air at sea-level. The temperatures of ice and steam under these conditions are found to be constant.

The temperature of melting ice is marked 32° on the Fahrenheit scale and 0° on the Centigrade and Réaumur scales. The temperature of boiling water at the sea-level is marked 212° on the Fahrenheit scale, 100° on the Centigrade, and 80° on the Réaumur. The interval between the freezing and boiling temperature of water is therefore 100 Centigrade, 180 Fahrenheit, and 80 Réaumur degrees.

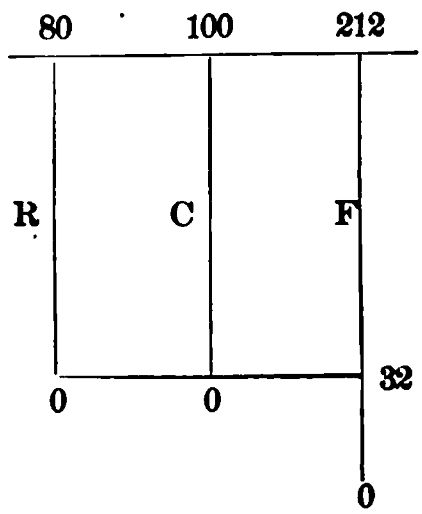


Fig. 128.—Scales Compared.

One Centigrade degree is thus equal to $\frac{9}{5}$ Fahrenheit degrees. If a Fahrenheit thermometer reads 60°, the temperature is therefore $60 - 32 = 28$ Fahrenheit degrees above the freezing-point. But $28°\ F = \frac{5}{9}\ 28°\ C$, or 15°·5 C; hence if C be the reading of a Centigrade thermometer and F that of a Fahrenheit at the same temperature,

$$C = \tfrac{5}{9}\,(F - 32)$$
$$F = \tfrac{9}{5}\,C + 32.$$

That is, to reduce a Fahrenheit to a Centigrade temperature, subtract 32 and multiply the remainder by $\frac{5}{9}$. To reduce a Centigrade to a Fahrenheit temperature, multiply by $\frac{9}{5}$ and add 32.

Thermometers used in physical experiments are usually provided with a cylindrical bulb, as shown in Fig. 127. In this form, they are both more sensitive and more convenient.

Maximum and Minimum Thermometers.—Other forms of thermometers are the maximum and minimum thermometers. As constructed for meteorological purposes they are shown in Fig. 129.

The maximum thermometer is like an ordinary mercury thermometer, except that the capillary tube has a narrow place near the bulb, through which the mercury is forced as the temperatnre rises. When the temperature falls, the mercury in the tube remains in position, showing the highest temperature reached.

The mercury is forced back into the bulb by whirling the thermometer on a pivot which pierces the metal frame near the top of the

scale. The lower instrument of Fig. 120 represents a maximum thermometer.

The minimum thermometer usually has alcohol as a liquid. The tube is of rather large bore; within it is a small glass rod below the surface of the alcohol. When the

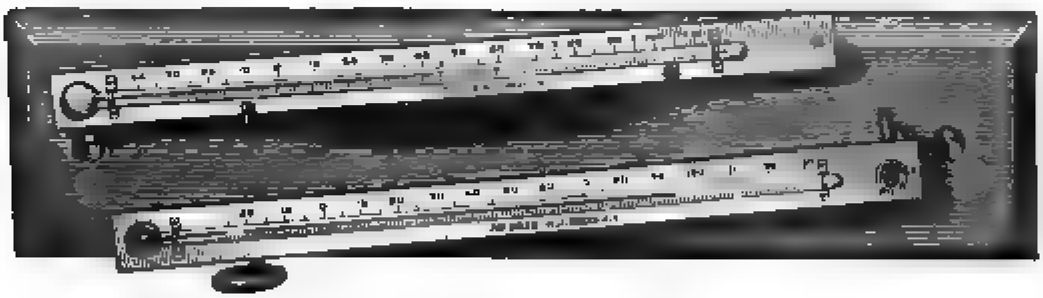


FIG. 120.—SET OF MAXIMUM AND MINIMUM THERMOMETERS. (LATEST U. S. SIGNAL SERVICE PATTERN.)

temperature falls and the surface sinks, the glass rod is forced along by the liquid and does not break through the film which bounds the surface of the alcohol. When the temperature rises again, the alcohol flows past the index, leaving it marking the lowest temperature reached.

The maximum thermometer records the highest temperature of the day; the minimum, the coldest temperature of the night. The mean of these temperatures is almost exactly the average temperature of the entire day. When in use, these thermometers are placed in a horizontal position.

LAW OF EXPANSION.

The Coefficient of Linear Expansion.—With the aid of the thermometer, the law of expansion of bodies can be examined. If a bar of iron be compared at different temperatures with a standard bar at a fixed temperature, it is found that the elongation of the bar per foot, per degree of temperature, is very nearly uniform at all ordinary temperatures. If this quantity be called a, the elongation of l feet for one degree would be l times as great, or la. If the elongation for l feet heated through one degree is la, for $t°$

the elongation would be alt. The final length l' would be the original length l, plus the elongation atl, or

$$l' = l + atl.$$

The quantity a is called the Coefficient of Expansion.

The coefficients of expansion for the Centigrade degree of eight different metals are given in the following table:

White glass	0·0000086	Copper	0·0000172
Untempered steel	0·0000108	Silver	0·0000191
Cast iron	0·0000113	Tin	0·0000217
Wrought iron	0·0000122	Lead	0·0000286
Tempered steel	0·0000124	Zinc	0·0000294

A tempered steel bar one foot long, when heated one degree centigrade, will become 1·0000124 feet in length. If one mile long, it would become 1·0000124 miles, the increase in length in the latter case being 0·0654 feet. When heated from 0° C. to 20° C., the mile bar would be increased in length 1·3089 feet.

As the Fahrenheit degree is only $\frac{5}{9}$ as long as the Centigrade, the coefficients of expansion for the Fahrenheit degree would be $\frac{5}{9}$ of those given above.

Temperature Compensation. — The coefficients of expansion of different substances being known, it is easy to arrange a system of rods which shall be compensated for changes in temperature.

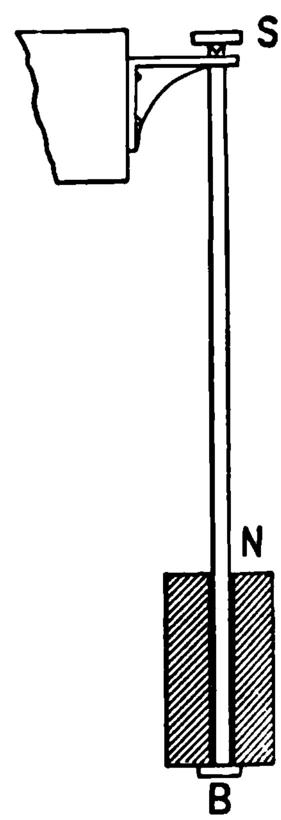


FIG. 130.—COMPENSATED PENDULUM.

Let S B (Fig. 130) be a glass rod 40 inches in length suspended at S and having a washer B cemented to its lower extremity. B N is a perforated cylinder of zinc slipped on over the rod and resting upon the washer. What must be the length B N of the zinc cylinder in order that its upper end shall always remain at a fixed distance from S when both rod and cylinder are equally heated or cooled? This problem may be solved by simple proportion; but it may also be stated as follows:

The elongation of the glass rod downward, when heated any number of degrees t, will be $0·0000086 \times 40 \times t$ inches. The zinc cylinder having a length l, when heated an equal number of degrees, will elongate upward $0·0000294 \times l \times t$

inches. These elongations are to be equal, or $8613 \times 40 \times t = 29417 \times l \times t$. Since t may be cancelled from the equation. we have $l = \frac{8613 \times 40}{29417} = 11{\cdot}7$ inches.

By such means pendulums are compensated, so that their lengths remain constant for varying temperatures.

The expansion thus far treated is the expansion of the linear dimensions of bodies, and the coefficients given in the table are called coefficients of linear expansion. It now becomes possible to determine the effect of expansion upon the volume of a body. This increase in volume is called

Cubical Expansion.—A cube of cast iron whose edges are one foot in length, when heated 1° C., would become slightly larger. The length of each edge would be increased by 0·00001125 feet. The cube would then be one having edges 1·00001125 feet in length.

The expanded cube might be conceived to be made up from the smaller one by placing three thin blocks upon three of the faces, as is shown in Fig. 131, where the thickness of the blocks is magnified 10,000 times. The thickness of each block being 0·00001125 feet, and the other edges being one foot in length, the volume of each slice $1 \times 1 \times 0{\cdot}00001125 = 0{\cdot}00001125$ cubic feet. The volume of the three slices is then 0·00003375 cubic feet. In order to complete the cube, we need three slender rectangular blocks laid along the edges shown in the figure, and a little cubical block in the corner. The three blocks will each have a volume of $0{\cdot}00001125 \times 0{\cdot}00001125 \times 1$, or 0·000000000126 cubic feet, so that the three will have a volume of 0·000000000378 cubic feet. The volume of the little cube required to fill out the corner will be $0{\cdot}00001125 \times 0{\cdot}00001125 \times 0{\cdot}00001125$, or 0·00000000000000142. Adding these three quantities, the volume of the expanded block will be—

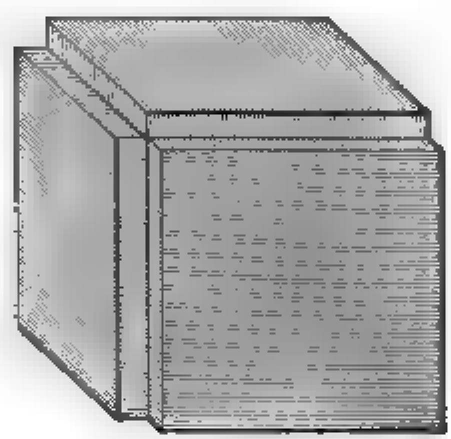


FIG. 131.—EXPANSION OF IRON CUBE.

Original block	1
Three slices	0·00003375
Three edge blocks	0·000000000378
Corner cube	0·000000000000001[illegible]

It is evident that the two volumes last written are too small to merit any consideration in comparison with the preceding one, which is itself insignificant when compared with the original volume. The cubic foot of cast iron may, then, be said to increase to 1·00003375 cubic feet when heated through one degree C.

Coefficient of Cubical Expansion.—The increase in volume of the unit volume, when heated through one degree, is called the coefficient of cubical expansion. The coefficients of cubical expansion of the substances named in the preceding table may therefore be obtained by multiplying their coefficients of linear expansion by three.

The coefficient of cubical expansion of white glass is 0·0000258; that of mercury is 0·000181. Hence, if a vessel holding 1 cubic inch is full of mercury at a temperature of 0° C., and is heated 1° C., the mercury will expand more than the glass by 0·000181 − 0·000026 = 0·000155 cubic inch. If glass expanded more than mercury, the column in a thermometer would fall when the temperature rises.

Fig. 132. Bottle and Glass Tube.

If a thermometer at any ordinary temperature be plunged into warm water, the column will at first sink and then rapidly rise. This is due to the fact that the glass bulb is heated and expands before the mercury is appreciably affected. If the thermometer be plunged into ice-water, the converse effect will take place.

The experiment may be made more striking by means of the apparatus shown in Fig. 132. This consists of a common two-quart bottle, filled with cool water, and closed by a stopper through which passes a glass tube. Just above the cork, the tube is drawn out fine. The upper surface of the water should be half-way up the narrow part of the tube. If the end of the finger be now placed against the side of the bottle, the liquid in the tube rapidly falls, show-

ing that the glass expanded and bulged out where the warm finger was applied. The experiments previously described with the thermometer can readily be made with this apparatus.

QUESTIONS. What instrument is used for measuring changes of temperature? Describe the Thermometer and its construction. How is the scale of the thermometer established? Name the three principal scales. What are the freezing and the boiling points respectively called in the Fahrenheit scale? What, in the Centigrade? What, in the Réaumur? How may a Fahrenheit temperature be reduced to its equivalent in centigrade degrees? A centigrade temperature to its Fahrenheit equivalent?

Describe the maximum and the minimum thermometer. How is the mean temperature of the day determined? In what way may the law of expansion be studied? What is the coefficient of linear expansion? Explain temperature compensation, and the practical use that is made of coefficients of expansion in the construction of the pendulum.

Define cubical expansion, and show how the coefficients of cubical expansion are obtained. Illustrate in the case of a cube of iron to which heat is applied. In the ordinary thermometer, which expands first, the glass or the mercury? Which expands more? Fully illustrate the principle. Why does heating the neck of the bottle uniformly in an alcohol flame loosen a tight glass stopper?

EXPANSION OF WATER AND GASES.

Water is a Marked Exception to the rule that bodies are expanded uniformly by heat. If water at the freezing-point be warmed, it contracts, and thus becomes more dense, until a temperature of 4° C., or 39·2° F. is reached, after which it expands. This can be proved by means of the

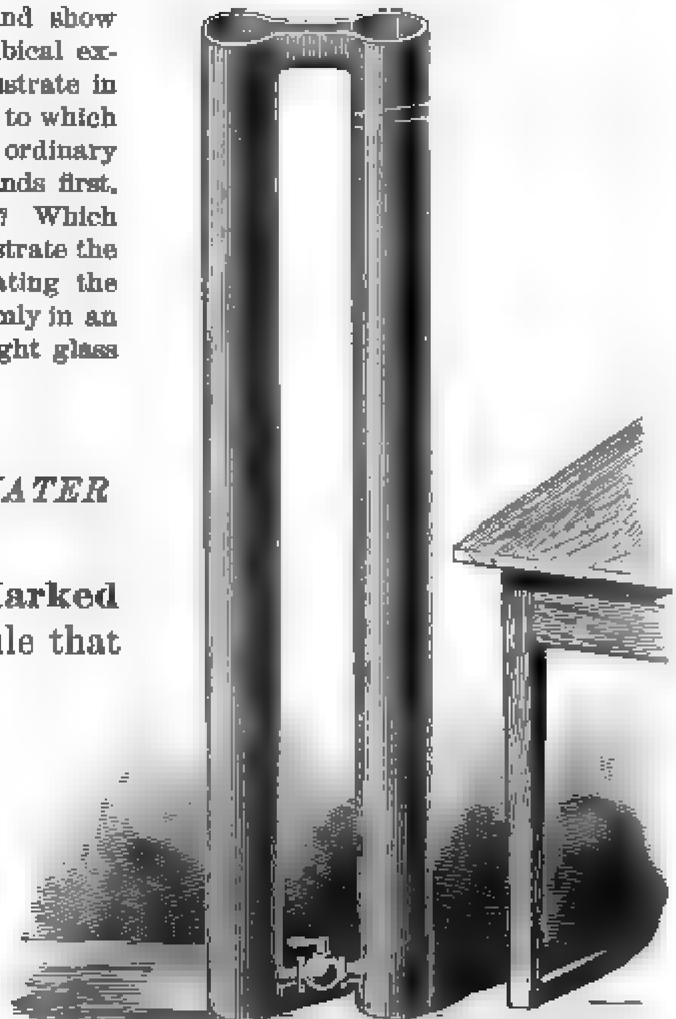


FIG. 133.—APPARATUS FOR DETERMINING THE TEMPERATURE AT WHICH WATER IS DENSEST.

bottle of iced water shown in Fig. 132. If the apparatus is placed in a warm room, and allowed to heat slowly, the column of liquid will descend at first and afterward rise.

The apparatus of Fig. 133 has been used to determine the temperature at which water is most dense. It consists of two tubes of galvanized iron, about four inches in diameter and five feet high. At the bottom, the tubes are connected by a pipe provided with a cock, by means of which they may be put in communication. At the top, they connect through an open trough.

If the left-hand tube be filled with water at 0° C., and the other with water at 8° C., so that the water stands about a quarter of an inch deep in the trough, and the tubes are then put in communication at the bottom, there will be no current in the trough. If the water in the left-hand tube be maintained at 0° C. by means of melting ice, and that in the other be allowed to warm a little, a gentle current will flow through the trough from right to left. This shows that the water must flow through the lower pipe in the opposite direction, and that the water at 0° C. exerts a greater pressure than that of the warmer column. By cooling the warmer water below 8° C. the currents are reversed. In this way, water at 7° C. is found to have the same density as at 1°, at 6° as at 2°, and at 5° as at 3°.

Phenomena of Freezing.—This property of water plays an important part in the preservation of the lives of animals inhabiting lakes and ponds. Only extremely shallow bodies of water are ever frozen to the bottom. After the temperature of a pond has been lowered to 4° C. (39·2° Fahr.) by the alternate sinking of heavier portions of water cooled at the surface, and rising of warmer and lighter particles from below, the surface layer, as it grows colder, begins slowly to expand. Hence it floats; and finally, when it is cooled to 0° C. (32° Fahr.), it crystallizes into ice, while the water below remains at 4° C. On freezing, the ice expands still more, the density of water at 0° C. being 62·41 pounds to the cubic foot, while that of ice at the same temperature is 58·05 pounds. Ice, therefore, always floats, and thus protects the denser water beneath, and the fishes and plants that inhabit it, from further reduction of temperature.

The pressure exerted by freezing water is irresistible. It often causes damage by the bursting of lead and iron pipes, and injures buildings and stone-work. The farmer avails himself of the expansion of water in freezing to break up the pieces of the soil which he plows into furrows in the autumn, and is often under the necessity of resetting, in the spring, fence-posts which have been loosened by the frost. Water freezing in the crevices of rocks splits them into fragments, as evidenced by the broken stones lying at the base of cliffs. In this way, the obelisk in Central Park, New York, is being defaced.

Expansion of Gases.—The apparatus shown in Fig. 132 serves to illustrate the expansion of gases. If it be filled with air, and the end of the tube be placed under water, the air will bubble out when the bottle is heated.

Experiments.—Fill a bladder with air, tie its neck, and place it before a fire; the heat will soon expand the confined air to such a degree as to burst the bladder.

The popping of grains of corn, the bursting open of chestnuts when roasting, and the crackling of burning wood, are caused in a measure by the expansion of the air within them. Bottles of effervescing drinks are kept in a cool place in summer, lest the heat expand the carbonic-acid gas in the liquid and break the bottles.

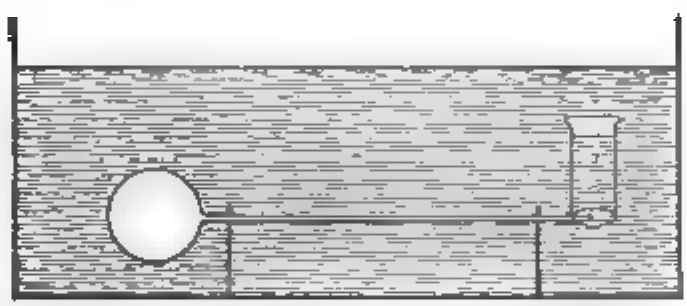


Fig. 134.—Illustrating the Expansion of Gases.

Fill a small tank with iced water. Keep the bulb of the air-thermometer in the water until it has cooled down to zero, and then immerse the whole tube, and fasten it in a horizontal position, as shown in Fig. 134. The bulb and tube are now full of air. Dip out cold water, and replace it with warm. Air will escape on account of expansion, and may be collected in a graduated tube. After having heated the air to any desired temperature, say 50° C., maintain this temperature until air ceases to escape, and then cool the water again to zero. Water will enter the bulb to replace the expelled air.

Lower the mouth of the collecting tube to the bottom of the tank, so as not to lose the gas, and take the bulb-tube out of the water, dry and weigh it. If the water in the stem runs out as the warm air strikes the bulb, it must be collected and weighed with the bulb. The

excess of this weight over that of the bulb alone gives the number of grammes, or cubic centimetres, of water in the bulb, or the number of cubic centimetres of air expelled. The expelled air, if cooled down to zero, should give the same result, by direct measurement.

The capacity of the bulb can now be found by filling the bulb and stem with water at zero C., and again weighing. If the empty bulb weighed 5·2 grammes, and when full weighed 120·5 grammes, then it holds 115·3 grammes of water, and the air originally in the bulb was 115·3 cubic centimetres. The expansion of the glass is so small in comparison with that of the gas that it may be neglected.

From these data, how would you find the increase in volume of 1 cubic centimetre of air, when heated 1° C.? This quantity is called the coefficient of expansion of air.

The Coefficients of Expansion of all Gases are nearly the same, under all pressures and at all temperatures. The value of the coefficient is $\frac{1}{273} = 0{\cdot}00366$. A cubic foot of gas at 0° C., when heated 1°, will become $1 + 0{\cdot}00366$ cubic feet. When heated to $t°$, it becomes $1 + 0{\cdot}00366\,t$ cubic feet. If t is 100°, the mass of gas which would have 1 cubic foot of volume at 0°, would become 1·366. In like manner, 1 cubic inch at 0° would expand to 1·366 cubic inches at 100° C.

If the Fahrenheit degree is used, the coefficient of expansion becomes $\frac{5}{9} \times \frac{1}{273} = \frac{1}{490}$. A quantity of gas heated from 0° to 273° C. would double in volume, if the pressure remained unchanged.

THERMAL UNITS AND SPECIFIC HEAT.

Quantity of Heat.—A Bunsen burner placed under a flask containing a quart of water, will soon raise the temperature of the water to the boiling-point. If we were to attempt to boil a thousand quarts of water in a vessel, by means of the same burner, but slight effect would be produced. It would require a thousand burners to bring about rapidly the same result. In this latter case, the amount of gas burned would be a thousand times as great, as would also be the amount of heat required.

Unit Quantity of Heat.—The unit quantity of heat is the heat required to raise the temperature of a unit mass of water through 1°. The actual magnitude of the heat unit depends upon whether the unit of mass be the pound, ounce, gramme, or kilogramme, and whether the thermometer be the Centigrade or Fahrenheit. To heat a thousand pounds of water 1° will require a thousand heat units; to heat it 5°, five thousand. If a Bunsen flame be applied to a flask containing 500 grammes of water, which it heats through 5° C. in one minute, the heat added to the water is 2,500 heat units a minute.

If 960 grammes of water at 2° C. be mixed with 800 grammes at 24 C., there will result 1,760 grammes of water at a temperature t. This temperature will evidently lie between 2° and 24°, and must be of such value that 800 grammes cooled from 24° to $t°$ will give up enough heat to heat 960 grammes from 2° to $t°$. The heat lost by the hot water is therefore $800\ (24-t)$. The heat gained by the cold water is $960\ (t-2)$. These values must be equal; or $800\ (24-t) = 960\ (t-2)$. Hence $t = 12$.

If equal quantities of hot and cold water be mixed, the resulting temperature will be the mean of the hot and cold temperatures. If the hot water be twice the amount of the cold, its change in temperature in reaching the temperature of the mixture will be half that of the cold water.

PROBLEM.—Suppose x grammes of water at a temperature of 75° to be mixed with 40 grammes of water at 3°. The temperature of the mixture is 15°. Find the value of x. The x grammes in cooling from 75° to 15° loses $(75-15)\,x = 60\,x$ heat units. The 40 grammes in heating from 3° to 15° requires $40\ (15-3) = 480$ heat units. Hence $60\,x = 480$, and $x = 8$.

PROBLEM.—If 100 grammes of water at 100° be put into 500 grammes of cool water at 10°, the resulting temperature will be t, the condition being $100\ (100-t) = 500\ (t-10)$ or $t = 25$.

The 100 grammes of hot water cools down from 100° to 25°, yielding 7,500 heat units. The 500 grammes heats from 10° to 25°, requiring 7,500 heat units.

If, however, 100 grammes of lead at 100° be mixed with 500 grammes of water at 10°, the resulting temperature will be found to be 10·56°.

The 500 grammes of water was heated only 0·56°, requiring $500 \times 0{\cdot}56 = 280$ heat units; hence 100 grammes of lead cooling from 100°

to 10·56° = 89·44°, yields only 280 heat units, or 1 gramme cooling 1° would yield 280 ÷ (89·44 × 100) = 0·0313 heat units.

Specific Heat.—The ratio obtained by dividing the amount of heat required to warm a given mass of any substance one degree by the amount required to heat an equal mass of water one degree, is called the Specific Heat of that substance. Thus the specific heat of lead is $\frac{0 \cdot 0313}{1 \cdot 0000} = 0 \cdot 0313$, the specific heat of water being reckoned as 1.

It is therefore evident that the specific heat is numerically equal to the quantity of heat required to raise the temperature of a unit mass of a given substance one degree. It must be understood, however, that specific heat is a ratio of two like values. As in the case of specific gravity, it is represented by an abstract number.

The Calorim'eter is an instrument for measuring quantities of heat. It is made in different forms, according to the uses for which it is intended.

Fig. 135 represents a calorimeter used for determining specific heat. The mass whose specific heat is to be ascertained, and whose weight and temperature are known, is placed in a copper receptacle, surrounded by a layer of ice, which the cooling mass partly fuses. The resulting water is drawn off through a pipe and weighed. Each gramme or pound of water represents a certain number of heat units lost by the cooling body and imparted to the ice. It requires about 80 heat units to fuse 1 pound of ice

FIG. 135.—PERSPECTIVE AND SECTIONAL VIEW OF THE ICE CALORIMETER.

(see page 248). The two inner compartments in the calorimeter are shielded from external heat by an outer layer of broken ice.

The specific heat of a number of substances is herewith presented:

Water	1·0000	Silver	0·0570
Ice	0·489	Tin	0·0555
Iron	0·1138	Lead	0·0314
Copper	0·0939	Mercury	0·0313

The fact that water has a high specific heat measurably determines the equable character of an oceanic climate. The water of the ocean may part with a large amount of heat in winter without getting cold, and may in summer receive a large amount without becoming warm, differing thus in a marked degree from *dry* soil. The effect of the sun in producing a high temperature is five times as great on dry sand as on water.

QUESTIONS.—State the general law of expansion. What exception is there to the law that liquids are expanded by heat and contracted by cold? Mention the temperature at which water is most dense. How is this determined? Explain what occurs when a pond freezes over. Show what part this provision of Nature plays in the preservation of fish-life. What examples can you cite to prove the great force with which water expands when freezing? Can you mention some familiar illustrations from your own experience? Name three temperatures that are important for you to remember in connection with water, and explain the significance of each. Illustrate the expansion of air by heat. What is the coefficient of expansion of a gas? How do the coefficients of expansion of gases differ?

Define a heat unit. On what does its magnitude depend? How do we estimate the temperature of a mixture of two quantities of water differing in temperature and weight? Of two quantities of lead and water? Of equal quantities of hot and cold water? Explain Specific Heat. Describe the calorimeter. In determining the specific heat of different substances, what is assumed as a standard? Compare the standard with the specific heat of other bodies. Explain the relative influence of land-masses and water in modifying climate.

FUSION AND VAPORIZATION.

Fusion illustrated.—Place a metallic vessel containing a pound of water over a Bunsen flame. If a thermometer inserted in the water shows a rise in temperature of 2° C. a minute, then the flame is imparting to the water two heat units a minute.

If the water be cooled down to 0° C. and a pound of ice

be placed in the vessel, the flame remaining as before, the temperature will continue at 0° C. until all the ice is fused. If a flame capable of imparting two heat units a minute to water at 0° C. be used, in a room where the temperature is 0° C., it will take forty minutes to melt the ice, showing that it requires eighty heat units to fuse one pound of ice.

To fuse a pound of ice requires as much heat as would raise the temperature of 80 pounds of water 1°, or 2 pounds 40°. If one pound of ice at 0° be placed in 10 pounds of water at 8°, the water will cool to 0°, and in so doing will yield heat just sufficient to fuse the ice.

PROBLEM.—Five grammes of ice at 0° C. are placed in 100 grammes of water at 90° C. Find the resulting temperature.

The heat required to fuse the ice is 5×80. The resulting ice-cold water is heated from 0° to $t°$, requiring $5\ t$ heat units. The total heat applied is therefore $5 \times 80 + 5\ t$. This heat is obtained from the hot water, which cools down from 90° to t, yielding $100\ (90 - t)$ heat units. Hence $5 \times 80 + 5\ t = 100\ (90 - t)$, or $105\ t = 8600$, or $t = 81{\cdot}9$.

When a solid is converted into a liquid, heat is absorbed. This is the principle on which freezing mixtures operate. Ice-cream, for instance, is frozen with a mixture of salt and snow or pounded ice; the latter is rapidly melted, and so much heat is absorbed in the process that the cream is brought to a solid form.

Differences in Fusibility.—Bodies differ widely in fusibility. Alcohol has never been rendered solid, its fusing-point being below the lowest attainable temperature. Mercury fuses at $-38{\cdot}8$ C.; ice, at 0° C.; lead, at 335°; and iron at about 1,500°.

Substances like paper, wood, and cloth, do not fuse at high temperatures, but are decomposed; while carbon has neither been fused nor decomposed. Bodies like carbon are said to be *refractory*. The number of refractory bodies has steadily diminished as methods of producing higher temperatures have been invented. Even carbon has been softened.

Alloys.—When fused metals are mixed, they frequently form a homogeneous metal, known as an Alloy, having different properties from any of its constituents. Alloys usually fuse at lower temperatures than any of the metals composing them.

Rose's fusible metal, consisting of 4 parts of bismuth, 1 of lead, and 1 of tin, melts at 94° C., while its most fusible component, tin, melts at 228° C.

TABLE OF FUSING-POINTS IN CENTIGRADE DEGREES.

Mercury	−38·8	Bismuth	264
Bromine	−12·5	Cadmium	321
Ice	0·0	Lead	335
Butter	+33	Zinc	422
Rose's metal	94	Silver	1,000
Sulphur	114	Gold	1,250
Tin	228	Iron	1,500

The following Laws of Fusion have been determined:

1. Every fusible substance under constant pressure fuses at a fixed temperature, called the fusing-point.

2. If the pressure varies, the fusing-point varies slightly.

3. The fusing-points of different bodies are different.

4. During fusion, the temperature remains constant. Increasing the temperature of the source of heat causes the body to fuse more rapidly, but does not raise its temperature.

5. To fuse a gramme of any substance under constant pressure requires a definite quantity of heat, which is different in the case of each fusible substance.

Vaporization.—If a vessel containing 1 pound of water be heated by a lamp capable of raising its temperature from 90° to 100° C. in five minutes, then two heat units will be added to the water each minute. When 100° is reached, the temperature will cease to rise, although two heat units a minute are still being added to the water. The heat is now being used in the vaporization of the liquid. It will require 268·5 minutes to evaporate (convert into a gaseous state) the pound of water with such a flame. Hence the heat required to evaporate the water is 537 units.

When a gramme of steam condenses to water without any change of temperature, the heat required to raise the temperature of 537 grammes of water 1° C. is evolved. Such is the source of heat in the steam coils used in warming buildings.

Phenomena of Evaporation.—Some substances, like musk, camphor, and ammonium carbonate, vaporize without going through a process of fusion. Moreover, a high temperature is not essential to vaporization. At ordinary temperatures, wherever a surface of water is in contact with the air, vapor is formed, and by this means the atmosphere becomes charged with moisture. Whenever vapor is formed, heat is absorbed, and cold is produced.

Hence, when the skin is moistened with a volatile liquid like ether or cologne water, a sensation of cold is experienced. Fanning cools the face by rapidly vaporizing the insensible perspiration which Nature has provided to regulate the temperature of the body. The cooling which accompanies the evaporation of sweat is one means of preventing the bodily temperature from rising above the natural standard of 98·5°. A high external temperature can, therefore, be borne as long as the skin responds with an increased secretion of perspiration. Sculptors have worked with safety in dry ovens at a temperature of more than 100° Fahr. above the boiling-point of water.

A drop of water let fall on a cold iron moistens its surface; if let fall on a very hot iron, it hisses and runs off without leaving any trace of moisture. In the latter case, the water does not touch the iron at all, but is separated from it by a layer of steam. Laundresses try their irons with wet fingers, to see if they are hot enough for use. On the same principle, jugglers plunge their hands into melted metal with impunity, by first wetting them. The drops of moisture on their hands assume a spheroidal form, and in this state evaporate much more slowly than at a lower temperature, keeping the molten metal from contact with the skin. This condition, which is assumed by liquids when exposed to the action of very hot metals, is known as the SPHEROIDAL STATE.

Phenomena of Boiling.—When a glass flask partly filled with water is heated, bubbles of air become visible on its sides. They appear at a low temperature, and may even be seen in a vessel of water standing in sunlight.

Finally, as the temperature nears the boiling-point, bubbles of steam begin to form at the bottom of the flask, rise, and collapse with a sharp, snapping sound. The upper portions of the liquid being somewhat cooler than those below,

the steam on rising condenses, and the walls of the bubbles, under the pressure of the atmosphere, come together with a crash. This sound of the collapsing bubbles is heard in the singing of the tea-kettle, and can be rendered more audible if steam from a boiler or coil is passed through a rubber tube into cold water. In a few moments the bubbles cease to collapse, but grow larger as they rise, and the liquid then begins to boil freely.

FIG 186.—PHENOMENA OF BOILING.

Boiling-Points differ.—As the fusing-points of substances vary, so do the temperatures at which they boil. Liquids which boil at low temperatures are said to be *volatile.*

If a test-tube containing ether be dipped into a beaker of water having a temperature of 50° or 60° C., the ether will begin to boil, and a thermometer placed in the ether will indicate a temperature of 35° C. If the water is warmer, the ether will boil more briskly, but its temperature will remain unchanged. The heat required to vaporize the ether will be taken from the water, which will therefore cool more quickly than it would if the ether were not evaporating.

Remember, it is dangerous to bring a flame near boiling ether.

TABLE OF BOILING-POINTS IN CENTIGRADE DEGREES.

Ammonia	−40	Water	100
Sulphur dioxide	−8	Mercury	350
Ether	35	Sulphur	447
Carbon bisulphide	48	Cadmium	860
Alcohol	78	Zinc	1040

Laws of Boiling.—From the experiments described above you have learned two important laws of boiling:

1. Every substance has a definite temperature at which it boils.

2. This temperature remains constant during boiling.

Distillation.—If any liquid is required to be separated from a salt which it holds in solution in such a manner as to save the liquid, the solution must be heated in a retort or boiler known as a "still," shown in Fig. 137. The vapor passes into a tube or worm (*d d*), surrounded by cool water or ice, and is thus condensed and collected in a vessel called a "receiver" (*g*). The salt remains behind in the retort. This process is called Distillation, and it is possible because some substances are converted into vapor at lower temperatures than others.

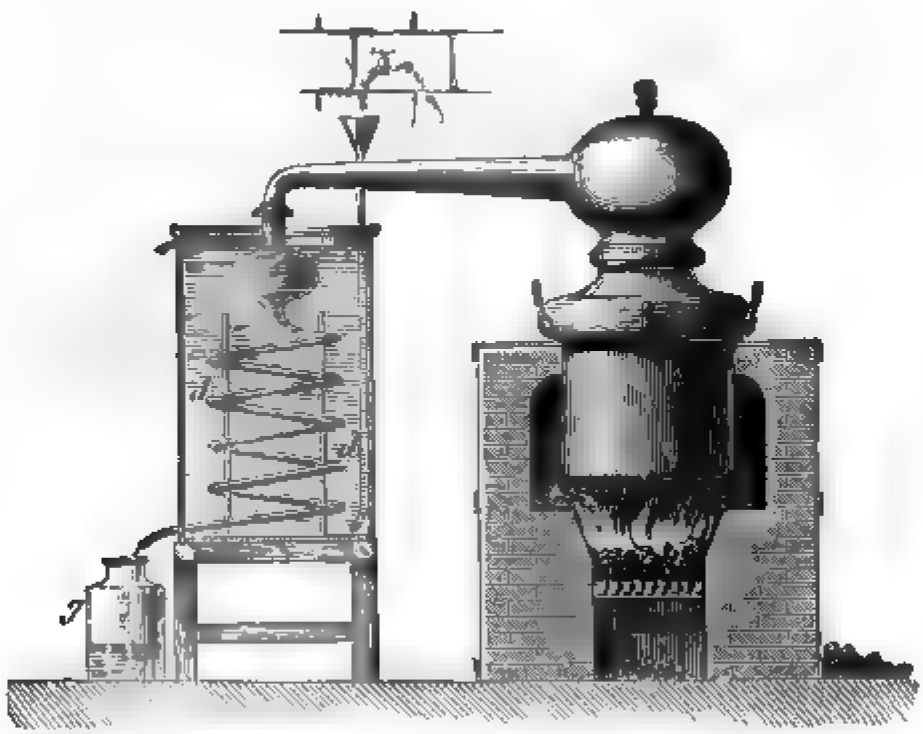


FIG. 137.—A STILL.

Alcohol and other volatile liquids can be separated from water by the same apparatus. The temperature of the retort is raised to or slightly above the boiling-point of the more volatile liquid, which then passes off as vapor, leaving the less volatile liquid behind in the retort. A little of the latter is indeed carried over, particularly toward the last, so that the first part of the distillate is sometimes collected in a separate vessel. Further purification can be effected by repeated distillation.

The pupil may readily improvise a simple still with a glass retort, retort-receiver, and common tin basin filled with cold water. If provided with a condenser (Fig. 10, page 230) he should arrange it, by the aid of corks and glass or rubber tubing, between the receiver and the retort. If water be placed in the retort and a flame applied till it boils, the steam formed will condense and trickle down into the receiver as chemically pure *distilled water*. Mere boiling will free water from gaseous impurities and also destroy the active principles of disease. It is safe, therefore, to drink boiled or distilled water during the prevalence of epidemics.

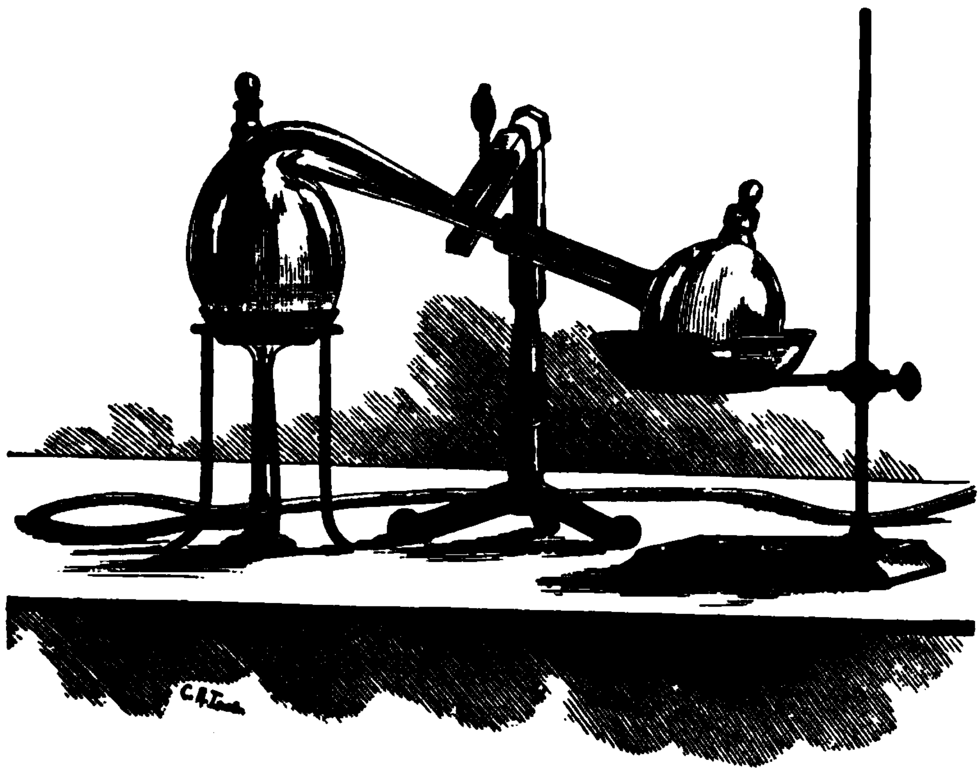


FIG. 138.—SIMPLE DISTILLATION.

Distill a small quantity of salt or sea water. The water in the receiver will have a disagreeable, flat taste, because it is not *aërated*, or does not contain air, as all drinkable water should. Shake it repeatedly in a large clean bottle and it will lose its unpleasant taste.

Introduce some fragrant roses into the retort with water and apply heat. The essential oil of the flowers, known as *attar*, will pass over with the steam, imparting a perceptible perfume to the water that condenses in the receiver. Large quantities of flowers are distilled in this way; the oils float and are removed. Dissolved in cologne spirit, they constitute perfumery extracts.

QUESTIONS.—What do you understand by fusion? Illustrate your answer. How much heat is required to fuse a pound of ice? How many thermal units? On what principle do freezing mixtures operate? Do all bodies fuse at the same temperature? Illustrate the difference, as regards their capability of being melted, in wax, mercury, alcohol, lead, gold. What is meant by a *refractory* body, and what is probable of all refractory bodies? Define an alloy. Formulate a general rule for the fusing-points of alloys. Sum up the laws of fusion.

What is vaporization? Mention the successive effects of heat on solids. May a body vaporize without fusing? Is heat essential to vaporization? Prove that cold is produced when vapor is formed. Why is this? Why does fanning cool

the face? Can you explain the office of perspiration. Describe the spheroidal state, and explain what practical advantage may be taken of the tendency of liquids to assume this condition. What is the temperature of water in the spheroidal state? ***Only about 95° C.***

Describe the phenomena of boiling. Explain the singing of the tea-kettle. Does the temperature of a liquid alter during boiling? Do all liquids vaporize at the same temperature? Contrast ether with water in this respect. What is distillation, and on what fact is the process based? What is an apparatus for distilling called? Describe the still. Explain how a simple still may be improvised. How may pure water be obtained by the use of this still? How, the essential oils of flowers? Why is not distilled water palatable?

INFLUENCE OF PRESSURE ON FUSING AND BOILING POINTS.

Boiling and Fusing Points vary according to the pressure. When a substance expands in solidifying, as in the case of water and some of the metals, the operation is resisted by atmospheric pressure. If water at 0° could be prevented from expanding by inclosing it in a vessel of sufficient strength, it would not freeze if cooled far below the freezing-point. If ice at 0° is put under a pressure of 20 atmospheres, it will fuse. In fusing, it diminishes in volume, and the increased pressure aids the operation. Water under such pressure would not freeze until it had cooled 0·15° below 0° C.

If the pressure on the ice be less than one atmosphere, it will not fuse at 0° but at a slightly higher temperature, because the aid which the operation derives from atmospheric pressure is diminished.

In the case of substances which contract in solidifying, all these statements would be reversed. Iron and type-metal expand when they solidify, and therefore fill molds and make sharp castings. The reverse is true of silver and gold. Coins made of these metals are therefore stamped with a die.

Water expands greatly on vaporizing. A cubic inch of water will make about a cubic foot of steam at one atmosphere pressure. The formation of steam is resisted by pressure; hence if the pressure be more than one atmosphere, the water must be made hotter than 100° before it will boil.

Conversely, if the pressure on the water is diminished, the water will boil at a lower temperature than 100° C. On Pike's Peak, at an altitude of 14,000 feet, where the barometer column may be only 18 inches high, the temperature of boiling water is only 188° Fahr., or 86·6° C. At such places food which is cooked by boiling water requires a much longer time for its preparation than at the sea-level.

Diminishing the pressure, therefore, raises the freezing-point of water slightly and lowers the boiling-point very much more. On this principle, vacuum-pans are now used for the evaporation of sugar solutions. Under the receiver of an air-pump, the boiling-point may even be brought down to the freezing-point, so that boiling and freezing may be going on at the same time.

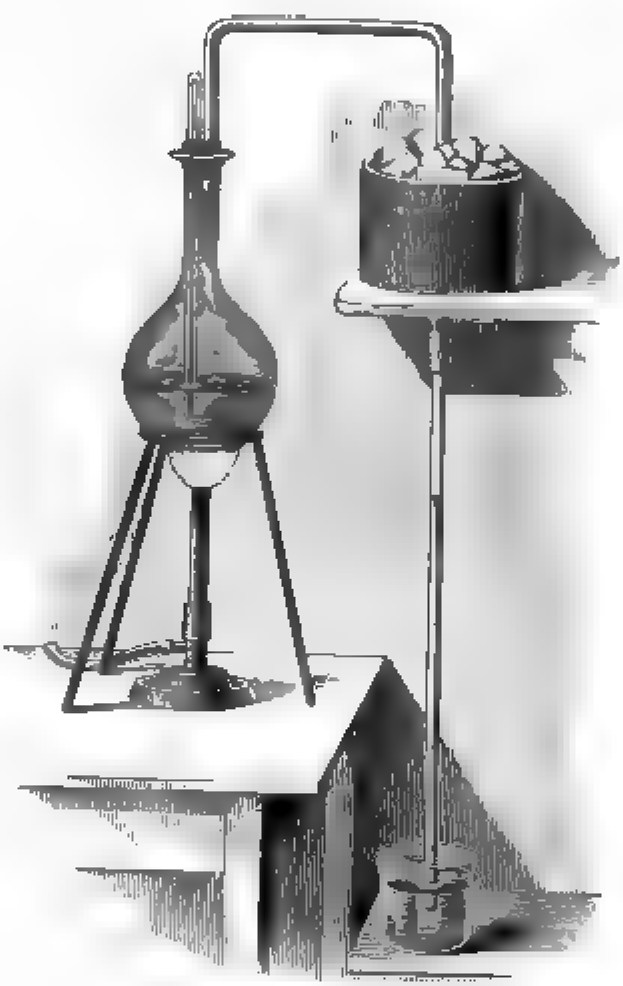


FIG. 139.—BOILING BELOW 100° C., 212° F.

Boiling at Temperatures below 100° C.—The boiling of water at a reduced temperature and pressure is illustrated in Fig. 139. A Florence flask half filled with water is closed tightly with a cork, through which pass a thermometer and a glass tube. The latter terminates just beneath the cork, and its other extremity is bent downward into a vessel of cold water standing at some distance below the flask.

The water in the flask is heated to boiling, and its temperature is noted by the thermometer when it discharges into the open air, and also when the lower end of the tube is immersed in the iced water. In the latter case, the water in the flask will be seen to boil at a temperature below 100°, and the iced water may rise in the tube. This rise of the water may be increased by clamping ice-blocks around the tube

and moving them up and down so as to cool the whole tube, or by surrounding the tube with ice in a vessel, as in the figure. The pressure within the flask is less than the atmospheric pressure by the pressure due to the column of water in the tube.

If the flame be removed, the lower end of the tube closed by the finger, and the flask then wrapped with a cold wet cloth, the water in the flask will begin to boil vigorously. This is due to the condensation of the steam in the upper part of the flask, which reduces the internal pressure and thus causes the water to boil below 100° C. If the flask is dipped in cold water, the experiment will be still more striking.

FIG. 140.—EXPERIMENT WITH THE PULSE-GLASS.

The same phenomenon may be shown with a pulse-glass containing colored ether (Fig. 140). One bulb is surrounded with ice or snow, and the other is then placed in hot water. The hot water causes the ether to boil, and the vapors are condensed in the second bulb.

Boiling under High Pressure.—In an ordinary steam-boiler, if the steam is not drawn off or condensed, evaporation apparently soon ceases. The steam space is then said to be saturated. Particles of water are indeed still flying off from the surface of the water into the steam space above, but this space is so full of particles that an equal number are continually plunging down upon the water surface and becoming part of the liquid. If the fire is now made hotter, the molecular agitation of the water is increased, so that particles are shaken loose from the water surface in greater numbers than they are returned; but this crowds the steam space more densely, and very soon equilibrium is again reached. The steam space is saturated at a higher temperature and pressure.

If steam is drawn off to feed an engine or to heat rooms, then evaporation will go on continuously, the boiling-point depending upon the resulting boiler pressure. With increasing pressure, there is no limit to the rise in the boiling-point except the strength of the boiler. The temperature of boiling water under pressures ranging from one to ten atmospheres is given in the following table:

Pressure in atmospheres.	Centigrade temperature.	Fahrenheit temperature.	Pressure in atmospheres.	Centigrade temperature.	Fahrenheit temperature.
1	100·0	212·0	6	156·2	313·2
2	120·6	249·1	7	165·3	329·5
3	133·9	273·1	8	170·8	339·4
4	144·0	291·2	9	175·8	348·4
5	152·2	306·0	10	180·3	356·5

In a locomotive-boiler, the pressure is about ten atmospheres, and the temperature of the water and steam in the boiler is then 180° C.

The following table, which forms the basis for observations on atmospheric humidity, gives the vapor pressure in inches of mercury in a boiler corresponding to various temperatures, from 0° Fahr. to 101° Fahr. Thus, at 32° Fahr., where the boiler is surrounded by ice-water, the vapor pressure within would be 0·181 inch of mercury.

STEAM PRESSURE IN INCHES OF MERCURY AT TEMPERATURES t.

t	Pressure.	t	Pressure.	t	Pressure.	t	Pressure.
0	0·043	33	0·188	56	0·449	79	0·990
2	0·048	34	0·196	57	0·465	80	1·023
4	0·052	35	0·204	58	0·482	81	1·057
6	0·057	36	0·212	59	0·500	82	1·092
8	0·062	37	0·220	60	0·518	83	1·128
10	0·068	38	0·229	61	0·536	84	1·165
12	0·075	39	0·238	62	0·556	85	1·203
14	0·082	40	0·248	63	0·576	86	1·242
16	0·090	41	0·257	64	0·596	87	1·282
18	0·098	42	0·267	65	0·617	88	1·323
20	0·108	43	0·277	66	0·639	89	1·366
21	0·113	44	0·288	67	0·662	90	1·410
22	0·118	45	0·299	68	0·685	91	1·455
23	0·123	46	0·311	69	0·708	92	1·501
24	0·129	47	0·323	70	0·733	93	1·548
25	0·135	48	0·335	71	0·758	94	1·597
26	0·141	49	0·348	72	0·784	95	1·647
27	0·147	50	0·361	73	0·811	96	1·698
28	0·153	51	0·374	74	0·839	97	1·751
29	0·160	52	0·388	75	0·868	98	1·805
30	0·167	53	0·403	76	0·897	99	1·861
31	0·174	54	0·418	77	0·927	100	1·918
32	0·181	55	0·433	78	0·958	101	1·977

The apparatus by means of which the values of the last table were obtained is shown in Fig. 141. A copper vessel, C, serves as the boiler. This is partly filled with water, into which four thermometers dip to various depths. The thermometers fit into air-tight packing in the cover, and the mercury can be read above. By means of a tube, A B, the steam space in the boiler connects with a glass globe contained in

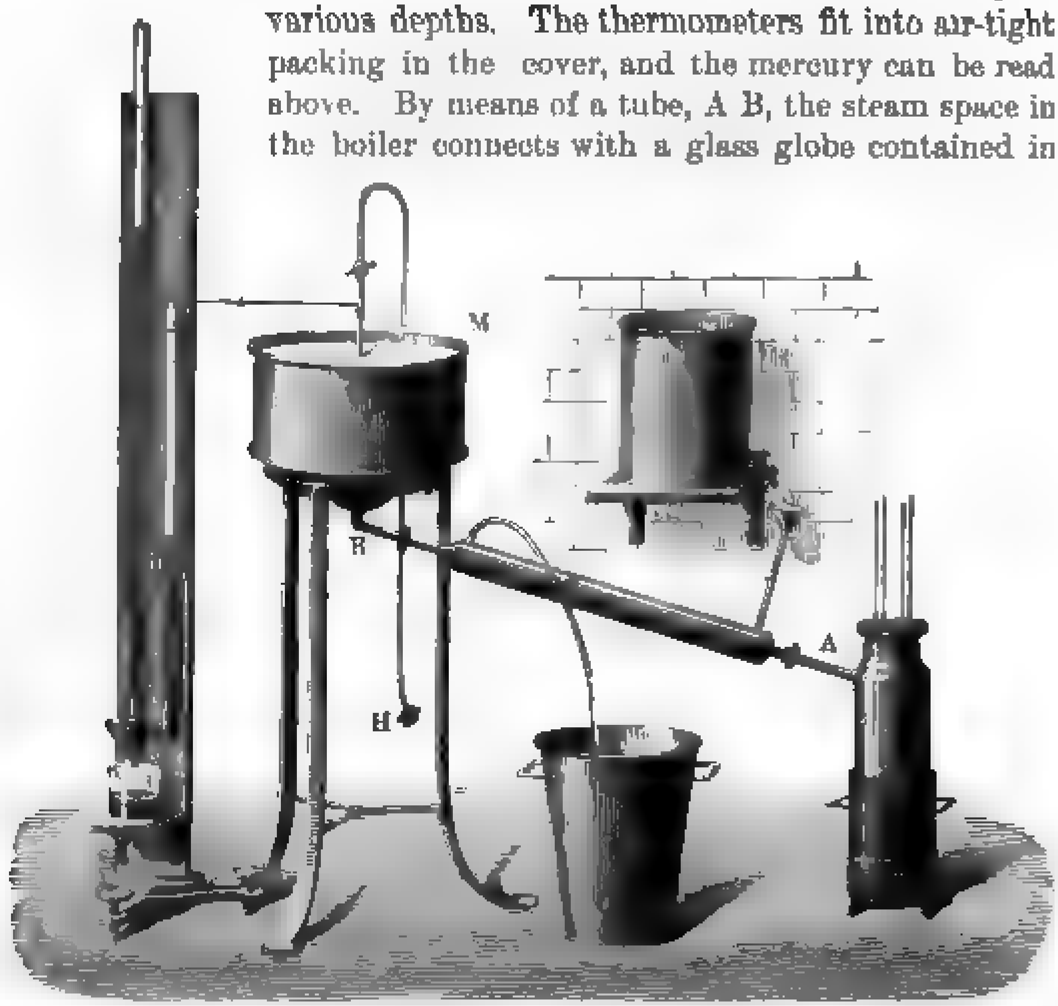


FIG. 141.—APPARATUS FOR MEASURING THE STEAM PRESSURE CORRESPONDING TO DIFFERENT TEMPERATURES.

the vessel, M, having a capacity of about six gallons and filled with air. To the upper part of the globe is attached a tube with two branches. One of these connects with an instrument which measures the pressure within the globe, tube, and boiler. The other communicates at H with a compressing or exhausting air-pump, by means of which the pressure can be varied at will. The globe in M is kept cool by surrounding it with water, and cool water is passed through the jacket which encompasses the tube A B.

When the water in C is boiled, the steam condenses in the pipe and globe and runs back into the boiler. Whenever the pressure is fixed, whether produced by the generation of steam or by the forcing of air into the globe, the temperature is always the same. For in-

stance, whenever the pressure inside is reduced to 0·22 inch of mercury, the water boils at 37° Fahr. and can not be heated above that temperature if the pressure is held constant. Making the flame under the boiler hotter will cause the water to evaporate more rapidly, but will not raise its temperature.

Pressure of Vapor below the Freezing-Point.—If the connection with the air-pump be opened so that the steam will drive all the air from the apparatus, and if the pipes be then closed and the vessel and boiler be put into ice-water, the steam will nearly all condense. There will, however, still be a pressure of 0·181 inches of mercury in the boiler. If the boiler be cooled to − 30° Fahr., the pressure will diminish to 0·009 inch of mercury.

Even at such low temperatures, ice slowly evaporates. In this way wet clothes become dry in freezing weather, and snow and ice slowly disappear, although the temperature may be continuously below the freezing-point. Probably if ice were cooled to −75° C. it would not appreciably evaporate, but would behave as lead or zinc at ordinary temperatures. At higher temperatures, these substances themselves may be vaporized.

QUESTIONS.—State fully the influence of pressure on fusing and boiling points. How may water be prevented from freezing at a temperature below 0° C.? Why can iron be molded better than either silver or gold? To how great a degree does water expand on vaporizing? Under what circumstances will water not boil at 100° C.? When will it boil at a lower temperature? Will it then cook food? The Dead Sea is 1,272 feet below sea-level. At what temperature does water boil on its shore? *At about* 214° *Fahr.*

Illustrate the boiling of water at a reduced temperature and pressure. The boiling of ether. In Fig. 140, page 256, if the cold bulb is removed from the ice while the other remains in the hot water, the apparatus will quickly explode. Why? Describe the phenomena of boiling under high pressure in an ordinary steam-boiler. How will the temperature vary? Under a pressure of ten atmospheres, what is the boiling-point of water? Name the only limit to the rise in the boiling-point. State the pressure in locomotive-boilers.

Explain the apparatus by which the steam pressures corresponding to different temperatures are ascertained. Why is the temperature always the same when the pressure is constant? What effect is apparent on increasing the heat applied to the boiler? What can you say of the vapor pressure below the freezing-point? Does ice evaporate at low temperatures? Is there any conceivable temperature at which snow and ice would not slowly disappear?

HUMIDITY OF THE ATMOSPHERE.—VAPOR PRESSURES.

The Atmosphere always contains Water-Vapor, but is rarely if ever saturated, so that no further evaporation can take place from bodies in contact with it. Steam from a tea-kettle is invisible for about an inch from the spout. It eventually condenses into a cloud of minute water-globules, which evaporate quickly In a saturated atmosphere, the cloud would not evaporate.

Atmospheric Humidity.—The weight of moisture in a unit volume of the air (in grains to the cubic foot, or in milligrammes to the cubic metre) is called its Humidity. It may be measured by means of the apparatus shown in Fig. 142.

Fig. 142.—Measurement of Atmospheric Humidity.

An aspirator bottle (C) nearly filled with water is provided with a siphon, through which the liquid may be drawn off. The air space in the bottle is connected, as shown, with two U-tubes containing fragments of chloride of calcium, or pumice-stone impregnated with sulphuric acid. When the water runs out of the bottle, air enters to supply its place through the U-tubes. The first tube, A, absorbs all the moisture from the air, while the second tube, B, intercepts any moisture which may proceed from the bottle.

Measure the volume of the water that has run out. This is equal to the volume of air which has passed through the apparatus. Tubes A and B are weighed before and after the experiment. The increase in weight gives the moisture in the measured volume of air, from which the moisture in grains to the cubic foot can be found. The humidity in grains to the cubic foot for saturated air is given in the accompanying table for various temperatures:

Degrees F.	Humidity.	Degrees F	Humidity.	Degrees F.	Humidity.
0	0·44	30	1·27	60	3·35
10	0·64	40	1 77	70	4·63
20	0·90	50	2·44	80	6 08

Dew-Point.—If a tin cup containing water is cooled gradually by adding small pieces of ice and stirring the water, moisture will finally condense on the outside of the cup in the form of dew. Drops of water are frequently observed on water-pitchers in summer. If the cup contains

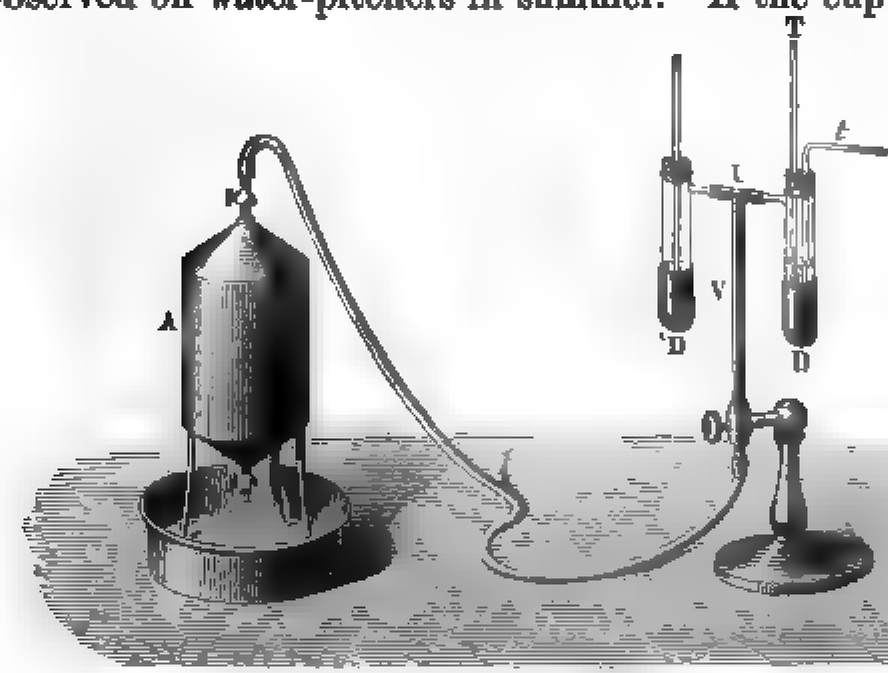


FIG. 143.—REGNAULT'S HYGROMETER.

a small fragment of ice, when the dew is first observable, remove the ice at once and observe the temperature of the water. Allow the water to stand until the dew disappears, and again observe the temperature, keeping the water stirred. The mean of these two temperatures is the *dew-*

point. If the air were to be cooled to this temperature, it would be saturated with moisture, and any further cooling would precipitate the moisture as a cloud.

The most suitable apparatus for determining the dew-point is Regnault's (*reh-no'*) hygrometer, shown in Fig. 143. It consists of two glass tubes, one of which (D) connects by means of a T-tube with an aspirator A. Both tubes contain thermometers fitted into their stoppers. The tube connecting with the aspirator has also an air-tube passing nearly to the bottom, and is in part filled with ether. When water runs from the aspirator, air is drawn through the ether, which vaporizes, cooling the remaining ether and the tube. When dew is observable on the silver thimble which caps the lower end of the tube, the water is checked and the thermometers are both read. The ether is now allowed to warm up until the dew disappears, and the thermometers are again read. The mean of the two readings of the cooled thermometer is the dew-point. The other thermometer registers at the same time the air temperature.

A simple apparatus, which will give very good results, may be made from an ordinary test-tube partly filled with ether, containing a thermometer, and a glass tube connected with a rubber coil two or three feet in length (see Fig. 144). Air is blown through the tube, vaporizing a portion of the ether and thus producing cold. Follow the same directions as in the case of Regnault's hygrometer, and determine the dew-point. The air temperature may be ascertained from an ordinary thermometer.

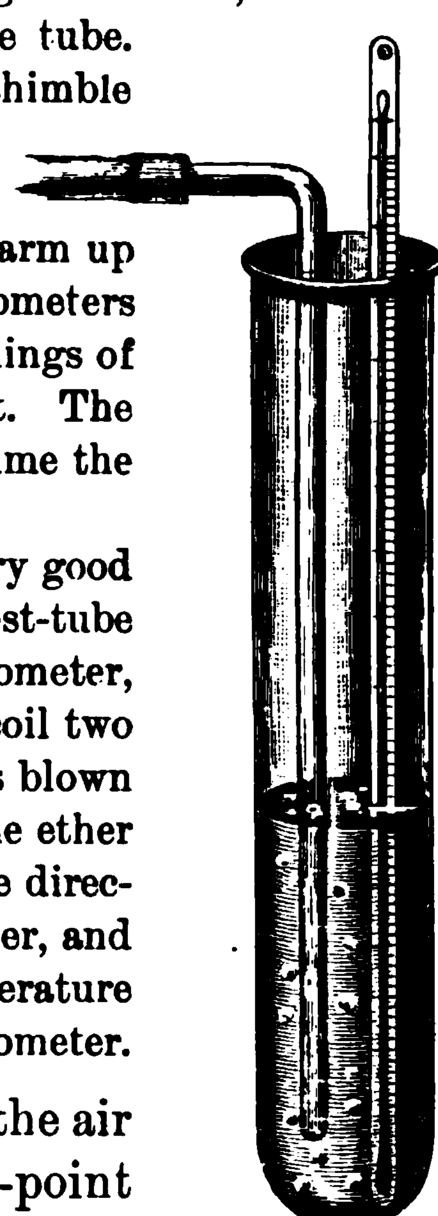


FIG. 144.—SIMPLE APPARATUS FOR DETERMINING THE DEW-POINT.

Relative Humidity.—Suppose the air temperature to be 70° F. and the dew-point 58° F. If the air were cooled down to 58°, it would be saturated with moisture. From the table of pressures of vapor (page 257) it will be seen that saturated vapor at a temperature of 58° has a pressure of 0·482 inch of mercury. This much of the atmospheric pressure shown by the barometer is due to moisture.

If the air were saturated with moisture at 70°, its vapor pressure would be 0·733 inch of mercury. The amount of moisture to the cubic foot would then be greater than it is at 58° in the ratio 0·733 ÷ 0·482. The amount of moisture actually in each cubic foot of air would be a certain fraction of what that cubic foot would contain if saturated. That fraction is 0·482 ÷ 0·733 = 0·65.

The relative humidity is the ratio of the amount of moisture in the air to the amount required to produce saturation. In the case instanced above, the relative humidity is 65 per cent. At 70°, the air could hold 4·53 grains per cubic foot. Hence, at 58°, it would hold 65 per cent of 4·53, or 2·94 grains.

When the Relative Humidity is low—that is, when the air is dry—we feel little inconvenience, even if it is very warm. Perspiration rapidly evaporates, and its latent heat is thus taken from the body, keeping it cool. If the air were saturated, its relative humidity would be 1·00, or one hundred per cent. No evaporation could then take place, and temperatures would prove fatal which could be endured with impunity in dry air.

When it is dry and hot, one feels cooler during exercise in the sunshine and open air than when sitting in the house. Why? In the vapor-laden atmosphere of the oceanic tropics we find a condition which interferes seriously with active bodily exercise.

In Meteorological Stations, relative humidity is usually determined by the psychrometer (*si-krom'e-ter*), or the wet and dry bulb thermometers, shown in Fig. 145. The bulb of one thermometer is covered with clean unstarched cotton cloth, which dips into a vessel of rain or distilled water. By capillary action the cloth is always kept wet. Evaporation of the water cools the bulb, the heat of evaporation being taken in part from it. If the air is dry, evaporation goes on more rapidly, and the depression of the mercury column is greater than when the air is nearly saturated.

If the air is wholly saturated, the wet bulb shows the same temperature as the dry one, both reading at the dew-point. The dry bulb indicates the air temperature. The wet bulb, however, always reads higher than the dew-point, except in the case just mentioned.

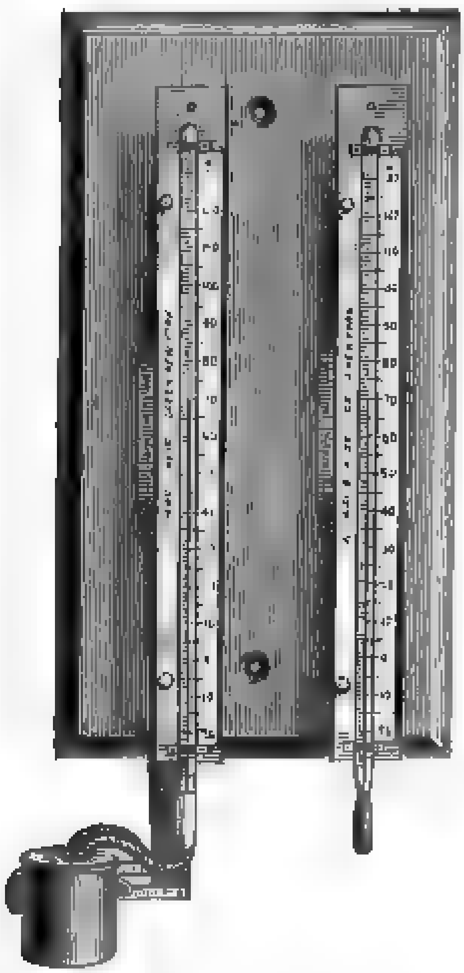
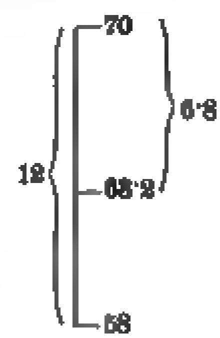


FIG. 145.—WET AND DRY BULB THERMOMETER. (LATEST U. S. SIGNAL SERVICE PATTERN.)

For example, in a certain case, the dry bulb read 70°, the wet bulb 63·2°, and the hygrometer at the same time showed the dew-point to be 58°. The wet bulb therefore read 6·8° below the dry bulb, and the dew-point was 12° below it—see diagram.



Now, if 6·8 were multiplied by some factor, the product would be 12, or the difference between the dew-point and the air temperature. The factor in this instance is evidently $\frac{12}{6·8} = 1·76$.

Unfortunately, this factor is different for different temperatures, so it must be determined for all ordinary temperatures. The numbers obtained are called Glaisher's factors. They are given in the table below:

Dry bulb. Temperature F.°	Factor.	Dry bulb. Temperature F.°	Factor.	Dry bulb. Temperature F.°	Factor.
Below 24°	8·5	30–31°	4·1	50–55°	2·0
24–25	6·9	31–32	3·7	55–60	1·9
25–26	6·5	32–33	3·3	60–65	1·8
26–27	6·1	33–34	3·0	65–70	1·8
27–28	5·6	34–35	2·8	70–75	1·7
28–29	5·1	35–40	2·5	75–80	1·7
29–30	4·6	40–45	2·2	80–85	1·6
		45–50	2·1		

If the temperature were 26° Fahr., the bulb would be covered with ice. In freezing weather it is better to remove the cloth and wet the bulb, allowing a thin film of ice to form upon it. If the wet bulb reads 24·5°, then the dew-point would be $(26-24{\cdot}5) \times 6{\cdot}3 = 9{\cdot}4$ degrees below the air-temperature. The dew-point would therefore be $26-9{\cdot}4 = 16{\cdot}6$. The value of the factor for 26 is taken midway between the values 6·1 and 6·5 in the table. This method is not quite accurate for low temperatures.

The Sling Psychrometer.—The psychrometer is most trustworthy when used in the wind. The air immediately around the wet bulb becomes moist, and evaporation from it will depend upon the quickness with which this air is removed by wind. The humidity of the air out of doors is therefore determined by means of a psychrometer in which the wet bulb is moved through the air until it shows a constant reading.

A simple and inexpensive whirling psychrometer—consisting of two thermometers with the degrees marked on the glass tubes and mounted securely on a light brass back—is used by the officers of the United States Signal Service. One thermometer is lower than the other, so as to bring the bulbs in different strata of air, and the apparatus is whirled about the person by means of a string. When wet, the muslin-covered bulb will fall to its permanent temperature in about two minutes.

A School-room Psychrometer.—The pupil may make a good psychrometer with two thermometers which read alike, and which can be bought for less than a dollar apiece. Any tinner can remove some of the metal around the bulbs so as to expose them similarly and permit the wrapping of one with cloth. Daily observations on the condition of the air in the school-room and the determination of the dew-point will be of interest to the pupils.

The Pressure of other Vapors corresponding to different temperatures has been carefully measured. In the table below, the values for four are given. The pressures are in centimetres of mercury, and the temperatures are in Centigrade degrees:

	TEMPERATURES CENTIGRADE.						
	− 20°.	0°.	+ 20°	40°.	60°.	80°.	100°
Mercury	...	0·002	0·004	0·008	0·02	0·04	0·08
Water	0·1	0·5	1·7	5·5	14·9	35·5	76·0
Alcohol	0·3	1·3	4·5	13·4	35·1	81·3	169·5
Ether	6·8	18·3	43·3	91·0	172·9	302·4	495·1

Any liquid boils in open air when its vapor pressure equals the pressure of the atmosphere. The bubbles which form in the liquid then pass off freely.

In the table above, it will be observed that at 100° (the boiling-point of water in open air) the vapor pressure of water is 76 centimetres (30 inches) of mercury. The vapor of alcohol will have a pressure of 76 centimetres of mercury at a temperature a little below 80°, the pressure at 80° being 81·3. The boiling-point of alcohol in open air is therefore a little below 80°. It is found by experiment to be 78°. Ether vapors have a pressure of 91 centimetres of mercury at 40°. The boiling-point of ether is therefore below 40°. It is found to be 35°.

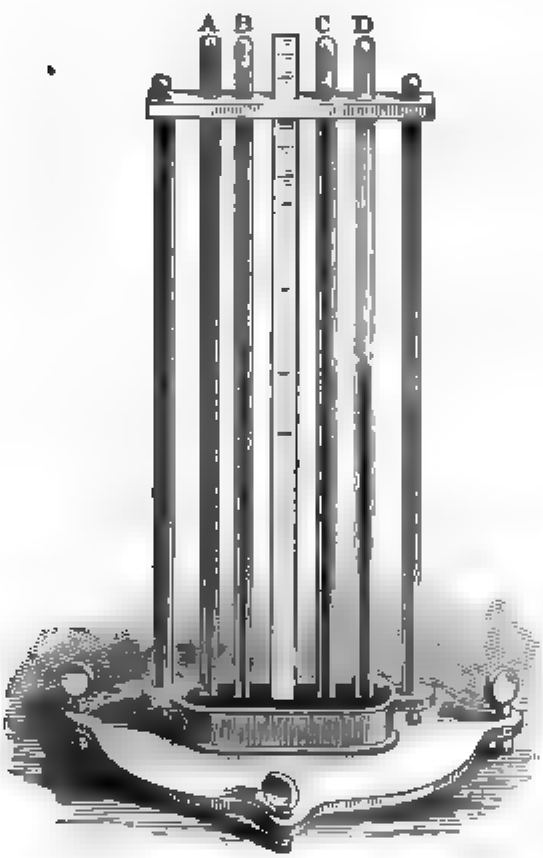


Fig. 146.—Vapor Pressures.

Experiment showing Vapor Pressures. — If four barometer-tubes are filled with mercury, the air being removed as completely as possible, and the open ends are then inserted in a vessel of mercury, the space above the mercury in each tube will be a Torricellian vacuum. If a little water be now introduced into one of the tubes (B, of Fig. 146), it will instantly vaporize on reaching the vacuum at the top. The column will also be depressed, showing that

the vapor presses the mercury downward. The water should be added in small quantities until the top of the column is perceptibly moist, which shows that the vacuum space has been saturated. The addition of more water would produce no further depression in the column, except such as might be due to the mere weight of the water.

Introduce alcohol in the same way into another tube (C) and the column will be depressed still more. Ether in a third tube (D) will cause a still greater depression. If the temperature of the mercury in the tubes is 20° C., which is a common temperature in school-rooms, and if all the air is removed from the mercury and liquids, the columns into which the three liquids were introduced will be depressed 1·7, 4·5, and 43·3 centimetres. These are the values for the vapor pressures at 20° given in the preceding table. The fourth barometer-tube (A) is also depressed 0·004 centimetre by the mercury vapor above it. This amount is hardly perceptible to the unaided eye.

QUESTIONS.—What is the source of atmospheric vapor? When may the atmosphere be said to be *saturated?* Explain the relation between saturation and evaporation. Define humidity. How may the humidity of the air be measured? State the number of grains to a cubic foot of saturated air at 0° Fahr.; at 80°. What does the difference prove? Explain what is meant by the dew-point. If the air is cooled below the dew-point, what takes place? Describe Regnault's hygrometer, for determining the dew-point. How may a simpler apparatus be easily constructed?

What is meant by relative humidity? When the relative humidity is low, is the air moist or dry? Is discomfort experienced? State a reason for your answer. Can high temperatures be better borne in dry or saturated air? How is the relative humidity determined by the officers of the United States Geological Survey? Is it possible for you to construct a fairly accurate psychrometer? How would you determine the dew-point from the readings of your instrument? What are Glaisher's factors? Suppose your dry bulb to read 26° Fahr., and your wet bulb 24·5°, what would be the dew-point?

When may a liquid be said to boil in the open air? What is the vapor pressure of water in inches of mercury at 100° C.? Of alcohol? Describe an experiment illustrating the vapor pressure of water, alcohol, and ether.

SOME SOURCES OF HEAT.

Relation between Heat and Mechanical Work.—Heat may be produced in a variety of ways by the performance of work. For example, a metal button may be rubbed against a board or woolen cloth, as shown on page 40.

The force required to make the button slide may be measured in pounds weight by means of a spring-balance, and this force, multiplied by the distance in feet over which it is exerted, will give the work done in foot-pounds. The button will quickly become warm, and if dropped into water will heat it. Some of the heat produced is lost in the wood or cloth, which also becomes warm.

If the friction is continued, the metal will keep warm indefinitely. This shows that heat is being continually produced by the operation, the button soon cooling to the temperature of surrounding bodies when the friction ceases.

Friction is a widely known Source of Heat. Even savages are familiar with the principle, and obtain fire by rubbing together pieces of dry wood. In a rapidly moving railway car, the heat produced by the friction of the axle turning in the box sometimes sets fire to the oily cotton-waste contained in the lubricating chamber, occasioning what is known as a "hot box." Ice itself may be melted by forcibly rubbing two pieces together at a temperature below the freezing-point.

Count Rumford observed that, in drilling a cannon, the metal became very hot. He surrounded the gun by a box containing about 30 pounds of water, which was heated to the boiling-point in two hours and a half. The drill was driven by a horse working on a capstan-bar. It is thus evident that food may be cooked and houses heated by steam generated by the work of horses. But, as Count Rumford observed, this would never pay, since more heat could be obtained by burning the food of the horse than from his work.

Joule's Determination of the Mechanical Equivalent of Heat.—The number of work units required to generate one heat unit—i. e., the number of units (foot-pounds) of energy equivalent to a unit quantity of heat—was determined experimentally by Joule (*jool*). He employed a copper vessel, B, filled with water and provided with a brass paddle-wheel, arranged somewhat like a churn. The paddle was driven by two falling weights, E and F, which were

suspended from rollers connected with the pulleys C and D, provided with friction-wheels. Cords wound on these pulleys were passed around the vertical paddle-shaft A. The two weights were on opposite sides of the churn, in order

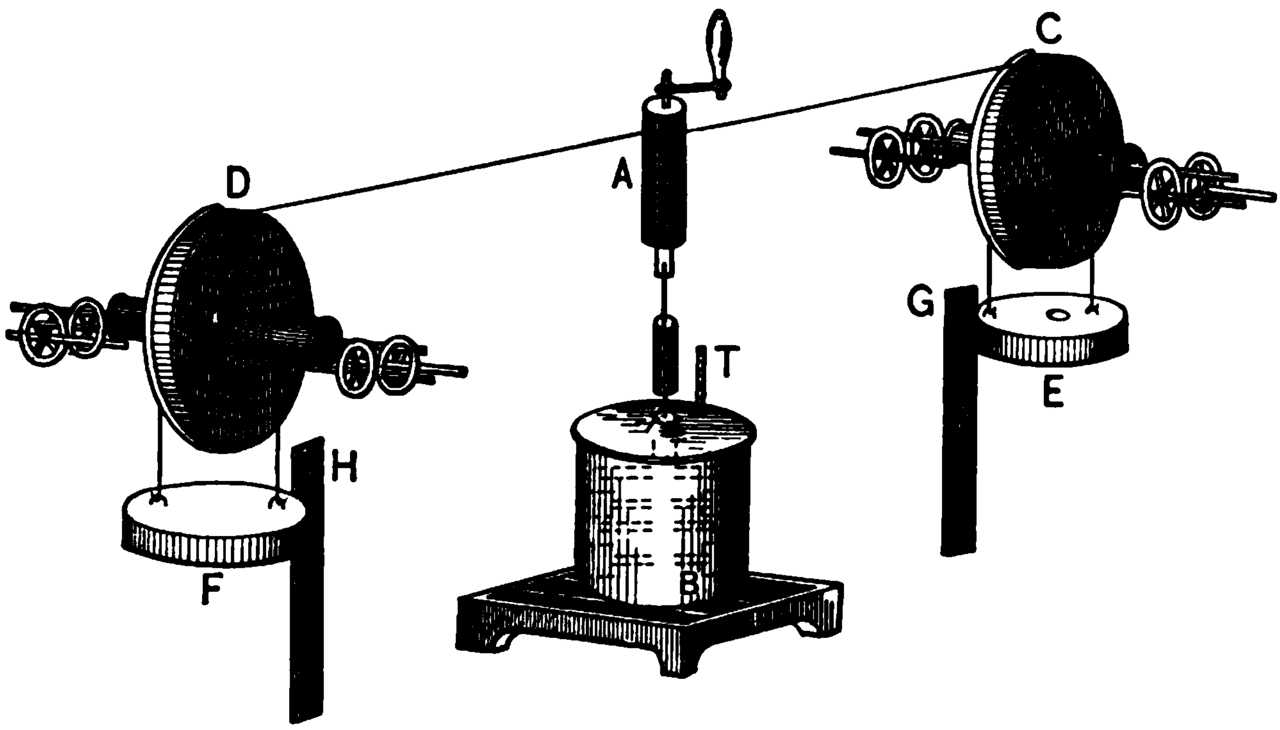


FIG. 147.—APPARATUS FOR MEASUREMENT OF THE MECHANICAL EQUIVALENT OF HEAT.

to avoid friction of the paddle-shaft in its upper bearing. When the weights fell and the paddle revolved, the water was heated by friction. A thermometer, T, indicated its temperature (see Fig. 147).

Various liquids were tried, and it was found that for every heat unit produced, 1,390 work units had been expended on the liquid by the falling weights, which were wound up again as fast as they reached the ground. The heating of one pound of water through one degree Centigrade is mechanically equivalent to the lifting of 1,390 pounds through a vertical distance of one foot, or of one pound 1,390 feet.

A laborer can perform 723,000 foot-pounds of work in ten hours, thus working at the rate of 20 foot-pounds a second. If such a workman were to be set to heating water by turning the crank of Joule's apparatus, he would produce one heat unit for every 1,390 work units in a day's work. In ten hours he would generate heat enough to raise the temperature of 518 pounds of water 1° C. The expense of heating water by this method would be enormously greater than by means of burning coal. The wages of the laborer would be at least one dollar, while the coal required to produce 518 heat units would be only about one ounce (see page 271).

The total daily mechanical and heat work of the human body is estimated at 7,216,000 foot-pounds, which, if expended in lifting the body, would raise it six miles against gravity.

Heat produced by Collision.—If a bullet from a heavily loaded rifle be fired into dry sand, it will be found to have become hot, or even fused. A rod of iron can quickly be raised to a red heat by the blows of a steam-hammer, and a marked rise in temperature is noticeable in lead pounded on an anvil (see page 40). Before lucifer-matches were invented, the blacksmith used to ignite sulphur to kindle his forge-fire with a nail hammered to a red heat. The old flint-lock gun was discharged through the agency of heat evolved by the striking of flint and steel together; the heat ignited the particles broken off by the blow, producing sparks which fired the powder in the pan.

The steam-hammer and the rifle-ball might have acquired the velocity with which they strike by falling in a vacuum from a certain height, and the work which is done in the blow of either may be measured by the work required to lift the moving body in question to this height.

A rifle-ball, for instance, would acquire a velocity of 1,500 feet a second by falling in a vacuum through a distance of 35,000 feet, or over 6·5 miles. If the ball has a weight of $\frac{1}{16}$ pound, and strikes with a velocity of 1,500 feet a second, the work done in collision is $35,000 \times \frac{1}{16}$, or 2,187 foot-pounds. (See the example on page 99.) Since we know by Joule's experiments that each 1,390 work units is equivalent to one heat unit, the heat liberated will be $\frac{2187}{1390}$, or 1·57 heat units. If we assume that half the heat is generated in the lead, the other half being imparted to the sand, then the lead will receive 0·785 heat unit. How much would the temperature of the lead rise?

To heat one pound of lead 1° C. requires 0·0314 heat units (see page 247). To heat $\frac{1}{16}$ pound 1° will require $\frac{0 \cdot 0314}{16}$ heat units. To heat the ball t° will require $\frac{0 \cdot 0314}{16}\,t$. This must equal 0·785; hence

$$t = \frac{16 \times 0 \cdot 785}{0 \cdot 0314} = 400.$$

As the melting-point of lead is 326, it is clear that the bullet must fuse before its temperature is raised 400 degrees.

Such experiments as that just described help to explain the nature of heat. When the mass in motion is suddenly stopped, the molecules of the body are thrown into vibration (see page 37). Vibration of their particles may thus be induced by rubbing bodies together, or by impact.

Heat due to Combustion.—When carbon burns, the chemical action is a combination of the carbon-particles with oxygen-particles. They fall together, as bodies fall to the earth, forming carbon dioxide (carbonic acid gas). It is found that the complete combustion of a pound of charcoal to carbon dioxide produces 8,080 heat units, or enough to heat 8,080 pounds of water 1° C. Since one heat unit is equivalent to 1,390 work units, the heat produced by the combustion of one pound of coal is equivalent to $8{,}080 \times 1{,}390 = 11{,}231{,}000$ work units.

If the pound of coal should fall through the distance of 11,231,000 feet, or 2,127 miles, with the acceleration which it has at the earth's surface, the heat produced on striking would be equal to that evolved by the burning of a pound of coal. The same heat would be produced by the falling of 100 tons of 2,000 pounds each through 56 feet.

The following table gives the heat produced by the burning of a pound of various substances, and in the third column is stated the distance through which 100 tons must fall to yield the same heat:

SUBSTANCE.	Heat units.	Fall in feet of 100 tons.	SUBSTANCE.	Heat units.	Fall in feet of 100 tons.
Hydrogen	34,462	240	Coke	7,000	49
Anthracite	8,460	59	Dry wood	4,025	28
Charcoal	8,080	56	Moist wood	3,100	22
Good bituminous coal	8,000	56	Iron	1,576	11

As in the operation of boiling, these combustions go on in air at definite temperatures. The bodies must be raised to the proper temperature before combustion takes place freely. The temperature at which iron will take fire and burn in air is higher than that necessary for charcoal.

The Heating Power of Coal, or of any other combustible solid, may be determined by means of the calorimeter shown in Fig. 148.

The coal, mingled with a fuel mixture, is tightly packed in a cylinder of heavy copper, C, having a length of four inches and a diameter of $\frac{5}{8}$ to $\frac{3}{4}$ inch. This cylinder is supported in a socket soldered to the bed-piece D. An outer cylinder, A, about $5\frac{1}{4}$ inches long and 2 inches in diameter, sets down over the fuel cylinder, and locks to the bed-plate as the bottom of a lantern locks to the globe. Four brass springs G serve to guide the cylinder A to its place, in order that the parts may be quickly fastened together. The fuse f is ignited, and, before the fuel begins to burn, the cylinder is locked in position and the whole apparatus is plunged under a weighed amount of water in the copper vessel B.

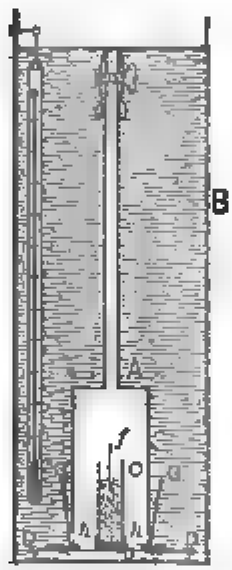


FIG. 148.—SECTION OF CALORIMETER.

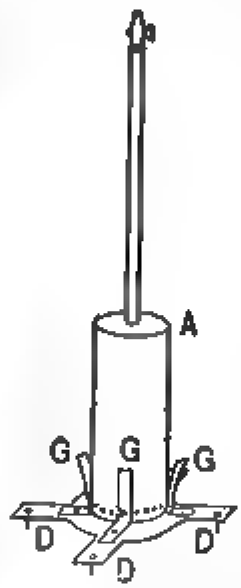


FIG. 149.

The upper cock being closed, no water can enter the cylinder A except a little at the bottom through the small holes h. Through these holes, the hot gases formed by the combustion issue, and rise in bubbles through the cooling water. After the combustion has ceased, the cock is opened at the top, and water rises and fills the whole apparatus. This should be blown out and mixed with the external water, in order to secure a uniform temperature. The temperature of the water having been read just before the operation, and subsequently at its close, the amount of heat liberated by the combustion is readily ascertained.

The fuel mixture consists of three parts by weight of potassium chlorate mixed with one part of niter. These substances should be in powdered form, dry, and thoroughly mixed. The mixture must be handled with some care. For each part of pulverized coal, about ten parts of the fuel mixture are required. Not over three grammes of coal can be used at one charge, and this should be tightly packed to prevent too rapid combustion.

The fuse is a narrow strip of blotting-paper, which has been dipped two or three times in a solution of potassium chlorate. Clamp the fuse

midway in a pair of pliers or a vise, and burn off the external coating of the salt from one end. Insert the unburned end into the charge. The fuse will burn slowly down to the part still coated with the salt, and thus give time to place the furnace in position under water. On a damp day, the fuse is likely to fail unless gently warmed.

For lecture purposes, the outer vessel B may be of glass, so that the operation may be seen. The experiment is a most impressive one.

If the whole apparatus, including the vessel B, weighs 1,260 grammes, the heat required to raise its temperature 1° C. (as it is of copper) will be 1,260 × 0·0952, or 120 heat units. If the vessel contain 3,000 grammes of water, then for each degree of rise in temperature the heat required would be 3,120 heat units.

A correction should yet be made for the heat generated by the fuse. This is best done by tearing four or five fuses to shreds, and packing them in a charge. The additional heat produced will be due to them, and the amount due to one can readily be found.

Animal Heat.—In all the organs of animals, oxidation, or burning of organic matter derived from food, is going on. The oxygen is taken into the blood through the lungs, and is evenly distributed to all parts of the body. When an animal is at work, it requires more of this oxygen, and hence breathes faster and consumes more of the organic tissue than when at rest. The chemical products of the oxidation taking place in the body, like those of ordinary combustion, are carbon dioxide and water, which pass off in part in the breath and through the skin. It is this oxidation that produces the heat of the body.

In the severe cold of arctic regions, life consists largely in an effort to eat and digest food enough to maintain the normal temperature. The Eskimos sustain their vital heat by a diet of fish-oil and seal's blubber, greasy food being rich in carbon.

In all animals in a state of health, the heat-producing and heat-destroying processes balance each other, and hence

a standard temperature is maintained—but this standard differs in different species. Birds and mammals, having a high vital heat, are classed as "warm-blooded animals." The mean temperature of some birds is above 111° Fahr. The standard in man is 98·6°, and any deviation from this standard is regarded as a sign of disease; temperatures below 97° Fahr. or above 106° Fahr. are extremely dangerous to life. Exposed parts, however, such as ears and fingers, are constantly cooled below the normal temperature of the blood and internal organs. Reptiles and fishes have low bodily temperatures, and are hence called "cold-blooded."

LAVOISIER'S EXPERIMENT.—Lavoisier (*lah-vwah-ze-ay'*) imprisoned a guinea-pig in a box surrounded by ice, placing the box in a room at the freezing-point. The heat of the animal's body fused 402·27 grammes (0·887 pound) in ten hours. To fuse one pound of ice requires 79 heat units; hence the animal produced $79 \times 0{\cdot}887 = 70$ heat units in ten hours. This would be equivalent to $1{,}390 \times 70$ work units, or 97,300 foot-pounds. The guinea-pig weighed four pounds. If the work had been employed in lifting him, it would have raised him through $\frac{97300}{4} = 24{,}325$ feet, or 4·6 miles in ten hours. Ten hours $= 36{,}000$ seconds. Hence the work performed in each second would have lifted the animal's body $\frac{24325}{36000} = 0{\cdot}67$ foot, or about 8 inches.

Plant Temperature.—It has long been known that plants evolve heat in connection with flowering, and this heat has been found to depend on the chemical processes which take place within the plant, transforming the matters derived from the soil into starch, sugar, and other products. By placing the bulb of a thermometer in contact with blossoms of *Arum* under a bell-jar, it has been established, not only that they have a temperature higher than that of the air, but also that the evolution of heat is variable. At 3 P. M., the air temperature being 15·6° C., the temperature of the flowers was observed to be 16·1° C.; at 5.45 and 6.15 P. M., when the air temperature had fallen to 15°, the thermometer in contact with the flowers recorded respectively 19·8° and 21°.

A liquid in which the yeast-plant is growing, acquires a temperature above that of the air. The same is true of germinating seeds, as illustrated in the malting of barley. Corn in the act of germination rises in temperature from 6·25° to 7·5° C. above the air; clover, 17·5° C.

Plants sometimes have a temperature lower than that of the air, and hence may suffer from frost when the temperature of the air is above freezing. The mean temperature of the trunks of trees is found to be higher than that of the air in autumn and winter, and lower in spring and summer.

Heat by Compression.—When a body, which expands when heat is applied to it, is compressed, it becomes hot, and gives off heat to surrounding bodies. Bodies which contract on being heated, become cool when compressed.

By violent and quick compression, enough heat can be set free from air to ignite tinder. This is done with the Pneumatic Syringe, consisting of a glass barrel and tightly fitting piston (see Fig. 107, page 205). In the extremity of the piston is a small cavity, in which some tinder is placed. When the piston is driven rapidly down, the air in the barrel is compressed, muscular energy is transformed into heat, and the tinder is set on fire.

QUESTIONS.—How may heat be produced by the application of work? What is Friction? Explain the heat of friction. State some familiar instances in which heat is produced by friction. How do savages kindle fires? How great a heat has been produced by boring a cannon? Explain Joule's method for determining the mechanical equivalent of heat. How many work units were found to be equivalent to a heat unit? Give some familiar examples of the production of heat by collision or percussion. How does a rifle-ball acquire the velocity with which it strikes, and how may the work implied in its blow be measured? Suppose an ounce bullet of lead to acquire a velocity of 1,500 feet a second by falling through a distance of 35,000 feet; what will be its rise in temperature when it strikes the ground? Does this imply that the lead ball may fuse?

Describe the combination of elements that occurs in the combustion of coal. Give the value in work units of the heat produced by the combustion of a pound of coal. Describe the apparatus and the process by which the heating power of coal may be determined. What is Animal Heat, and to what is it attributable? Compare the chemical changes taking place in the living body with ordinary combustion. How is animal heat sustained amid arctic cold? Why are not meat and greasy food an appropriate diet for summer? Explain why a standard temperature is maintained in all animals. What is said of animal heat in different species? State the normal temperature in man, and deviations that are dangerous. The mean temperature of birds.

Narrate the results of Lavoisier's experiment in regard to animal heat. What has long been known in connection with plants? On what does the heat of plants depend? Do plants ever have a temperature lower than that of the air? Illustrate. What can you say of compression as a source of heat?

DIFFUSION OF HEAT.

Heat always tends to pass from warmer to colder bodies. If several bodies near one another have different temperatures, those that are hot become colder, and those that are cold become warmer, until all have a common temperature. If all bodies had the same temperature, we should know nothing of heat. This equalizing of temperatures is brought about in three ways, viz., by Conduction, by Convection, and by Radiation.

Conduction.—Thrust one end of a pin into a gas-flame. It will quickly become too hot to be held in the hand. The heat enters the metal pin at the end kept in the flame, and is transmitted along its whole length. A splinter of wood, a roll of paper, a glass tube, or a platinum wire, may be held with comfort by one end while the other is burning or fusing. The brass pin is said to be *a better conductor* than the glass tube or platinum wire.

Among metals, silver, copper, and gold, are examples of good conductors; while bismuth, German silver, and platinum, are bad conductors. You can understand why articles made of certain metals feel intensely cold in winter. It is because they conduct the heat of the hand rapidly away.

The principle upon which heat is conveyed by conduction is that of communication from particle to particle of the body receiving it. As each particle is set in more violent motion, it imparts this motion to the more slowly moving particles next to it, these to others, and so on, until those farthest from the source of heat are reached.

The relative conducting powers of some of the more common metals are here given, that of silver being taken as 100:

Silver	100	Steel	12
Copper	74	Lead	9
Gold	53	Platinum	8
Tin	15	Bismuth	2

The Principle of Conduction applied to Clothing.—When heat is being drawn rapidly from our bodies, the sensation of cold is produced. Bad conductors should, therefore, be chosen for clothing materials, that the animal heat may be retained about the body and dangerous chilling prevented. Wool and silk meet this condition perfectly, and cotton is to a certain extent safe; but linen is a good conductor, and should never be worn next the skin, as it cools the body too rapidly in perspiration.

Hair is a bad conductor, and hence is an equally good protector against heat and cold. Explorers, in tropical as well as arctic regions, allow the hair and beard to grow. On the approach of winter, Nature provides for the protection of the lower animals by a heavy growth of hair, wool, or feathers, and by a jacket of fat, which is also a non-conductor.

Conduction in Liquids.—Liquids, as a rule, are poorer conductors than most solids. Fill a test-tube with water, as shown in Fig. 150, place a fragment of ice at the bottom, and hold it down with a glass rod. If a flame now be applied near the surface, the water there may be boiled, while the ice, surrounded by the denser cold water below, remains unfused at the bottom. If the ice be allowed to float to the top of the tube, the heat being applied at the bottom, the heated water will rise to the top and the cool water from the ice will descend. This mixture of the cold and hot particles will prevent the water from boiling until the ice has fused.

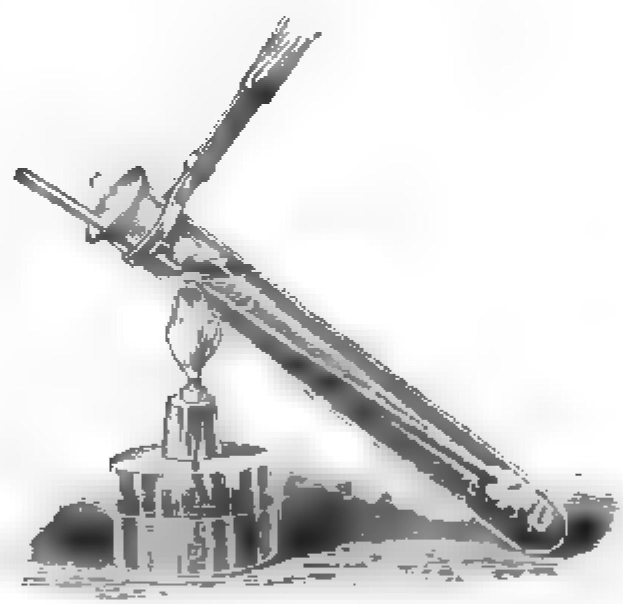


FIG. 150.—WATER A NON-CONDUCTOR.

Fig. 151 also shows a method of testing the conducting power of liquids. The stem of an air thermometer passes through a cork fitted into the neck of a glass funnel. The lower end of the stem dips into a vessel of water. Fill the funnel with water so that the bulb is covered to the depth of half an inch. Pour a little ether upon the water in the funnel and ignite it (after having stoppered and removed the ether-bottle). While the surface of the water is considerably heated, the thermometer will be but slightly affected. This shows that heat penetrates water by conduction very slowly.

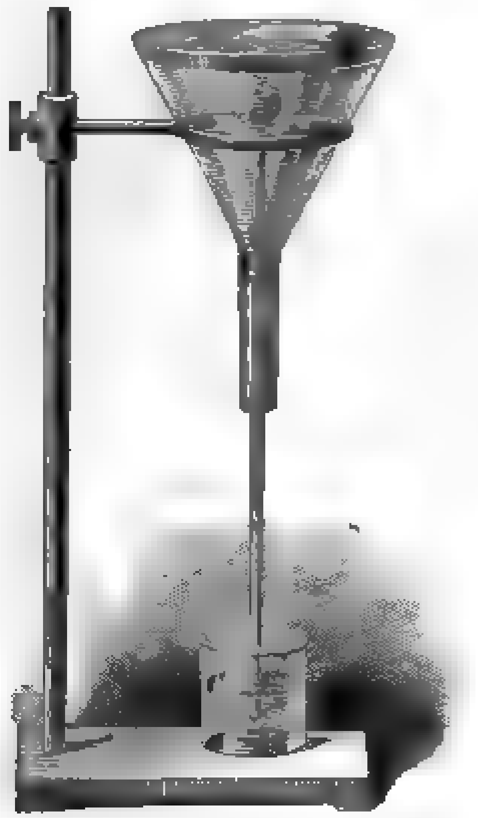


Fig. 151. Air Thermometer in Funnel of Water.

It is doubtful whether gases have any true conducting power. The difficulty of studying this point arises from the impossibility of preventing the heating of the gas by convection, the next method of diffusion to be discussed. It is partly because their interstices are filled with air, that woolen fabrics are poor conductors.

Snow is a bad Conductor, and hence is popularly said to keep the earth warm. Its flakes are formed of crystals, which collect into feathery masses, imprisoning air,

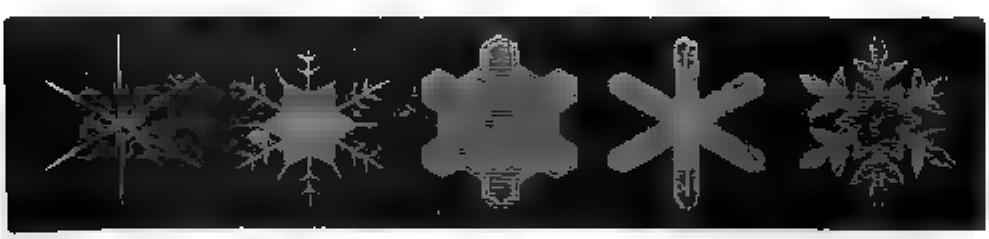


Fig. 152. Types of Snow-Crystals.

and thus interfere with the escape of heat from the earth's surface. The winter dwellings of the Eskimos are shielded from the cold by their snow covering. Hunters surprised

by night in the forest dig holes in the snow for protection, and the instinct of certain animals leads them to take advantage of the same shelter. A covey of grouse will dash into a snow-bank, and remain there in safety when the outside temperature is dangerous to life.

Convection.—Liquids and gases are heated mainly by Convection, or transmission by means of currents. The air immediately in contact with a hot stove, being heated and thereby made less dense, ascends, and is replaced by colder and denser air from below. The warm column rises to the upper part of the room, and then, descending beside the walls, loses part of its heat and approaches the stove again along the floor.

Similar currents are produced in a test-tube or tall beaker of water when heated over the flame of a spirit-lamp. The currents can be made apparent by placing a little bran or sawdust in the water.

Radiation of Heat.—If we stand in front of a fire or hot stove, we experience a feeling of warmth. This is not due to the fact that the air in contact with us is warm, since if a screen be interposed the heat ceases to be felt. Such transmission of heat is known as Radiation.

The pupil must understand, in this connection, that the heat of the radiating body is wholly transformed, at the instant of radiation, into Radiant Energy (see pages 38 and 293). Throughout the space between the radiating and receiving object, the radiation is a form of energy entirely distinct from heat. The heat of the open fire, for example, transformed into radiant energy as just stated, passes on to us as radiant energy, and is *retransformed into heat when it strikes our bodies.* Radiation, therefore, strictly speaking, is the transmission of radiant energy, and not of heat. For the sake of brevity, we speak of heat radiation.

The Power of radiating Heat varies in different bodies. Lamp-black, paper, and glass, are good radiators; polished tin and silver, the reverse; but any metal that is painted becomes an excellent radiator. Water will remain hot a longer time in a smooth silver cup than in a china

one, provided neither is in contact with a conductor. The hearth-stone, when the fire is lighted, receives heat abundantly from the blazing fuel and radiates it freely to the surrounding air. Why does the hearth-stone now feel warmer to the bare foot than the rug?

Good radiators are also good absorbers, and *vice versa.* The bottom of the tea-kettle is allowed to remain thinly coated with soot to counteract the non-absorbing property of the bright new surface. A very thin film of metal interferes with radiation and absorption. The Chinese are aware of this, and gild their silk umbrellas to keep out the heat of the sun.

Radiation in a Vacuum.—If a thermometer be sealed into a glass globe, the mercury-bulb being at the center of the globe, and if the globe be then exhausted as completely as possible, heat will nevertheless affect the thermometer even better than when the globe is filled with air.

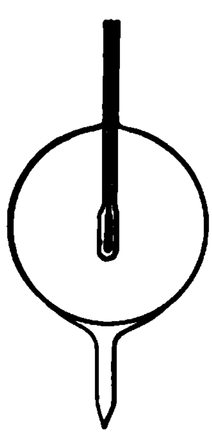


FIG. 153.—THERMOMETER IN A VACUUM.

This may be shown (Fig. 153) by dipping the globe into hot water. The thermometer will at once rise. A hot cloth wrapped around the thermometer stem, outside the bulb, will not appreciably affect the instrument; but, if the cloth be wrapped around the globe, a rise will instantly be observed. This shows that the heat is radiated from the sides of the globe to the thermometer-bulb, and is not conducted along the stem. Solar heat may be concentrated upon the bulb by means of a lens; light and heat will both traverse the so-called vacuum.

The heat which comes to us from the sun passes through the interplanetary space, which is substantially a vacuum (see page 293).

Law of Distance.—A hot ball of metal transmits heat in all directions, and will cool unless continually supplied with heat. A certain amount of heat leaves the ball during each second. Imagine a spherical concentric surface surrounding the ball, its radius being three feet (Fig. 154). All the heat which leaves the ball each second will pass through this surface each second, if the intervening medium is not heated.

If we imagine a second concentric spherical surface, having twice the radius of the former, the heat which passes through the first surface every second would also pass through the larger surface in the same time. But the outer surface has four times the area of the inner, since, by a geometrical law, the surfaces of spheres are as the squares of their radii. The heat which would fall upon a unit area of the inner surface would therefore spread over four units of area at twice the distance, nine units of area at three times the distance, etc. Hence the heat per unit area at distances 1, 2, 3, 4, will be in the ratio of 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, etc.

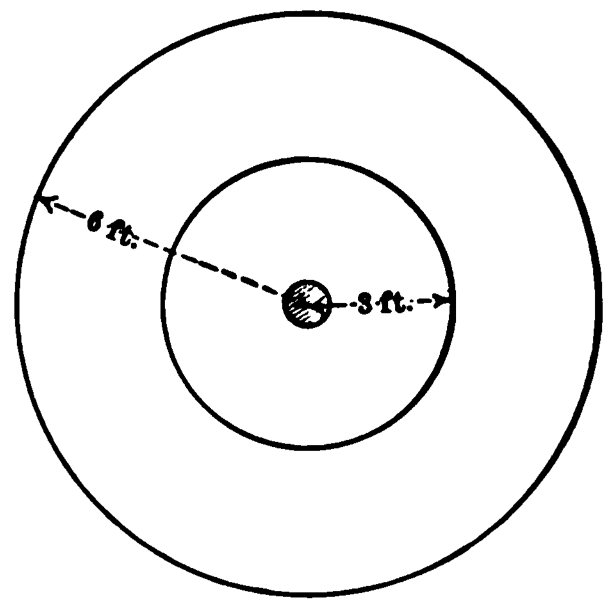


FIG. 154.—LAW OF DISTANCE.

The heating effect of a small radiant mass upon a distant object would thus vary inversely as the square of the distance. A similar law applies in the case of light and sound radiated from a point.

Law of Cooling.—A hot body surrounded by cooler bodies radiates its heat and cools down to the temperature of its surroundings. When the difference in temperature is not over ten degrees, the heat radiated per minute (and therefore the fall in temperature per minute) is very nearly proportional to the difference in temperature between the hot body and the surrounding bodies.

When a body is exposed to any source of heat, it rises in temperature, but at the same time it begins to radiate more heat. It will finally reach a temperature at which the amount of heat radiated per second will equal that received in a second. Its temperature will then cease to rise.

In winter, heat radiates from the human body more rapidly than in summer, because the difference in temperature between the body and the surrounding air is then great. In the arctic regions, the drain upon the animal heat of the body is very severe, and a large part of the energy of the inhabitants is expended in keeping themselves warm (see page 273).

In the torrid zone also, radiation plays an important part. The heat of the body is not so rapidly radiated as in temperate regions.

The inhabitants, therefore, live on light vegetable foods, and are sluggish and indolent in their habits, in order to avoid overheating.

QUESTIONS.—What is meant by the diffusion of heat? Explain what takes place when several bodies having different temperatures are brought near one another. By what three processes are temperatures equalized? Describe the principle and effects of Conduction. Mention some poor conductors; some good conductors. Explain why certain metallic articles feel intensely cold in winter. Why are cooking utensils provided with wooden handles? Are stone and marble good conductors? Prove it. What lesson may you learn from this? Fire-brick is a bad conductor; why are stoves and furnaces lined with it? What can you say of the relative value of materials used for clothing? Why is an eider-down quilt incomparable as a cover at night? What is the value of hair? How does Nature protect the lower animals from cold? Do you think the bark of a tree fulfills any such purpose? Do fur garments impart heat to the body? Why is flannel used to wrap ice in summer?

Which are the better conductors of heat—liquids or solids? Liquids or gases? Prove that water is an imperfect conductor. Illustrate the non-conducting property of snow. Did you ever notice in a building heated with steam that the pipes are wrapped with asbestos or felt and covered with canvas? Why is this? Describe Convection; how may it be illustrated?

Explain Radiation. Of what is it really the transmission? Exactly how is heat communicated from hot objects to our bodies? What is Radiant Energy? Show how the power of radiating heat varies in different bodies. What is the relation between radiation and absorption? The conducting pipes in steam-engines are never painted; why? Prove that radiation takes place in a so-called vacuum. State the law of distance in regard to radiation? How does heating effect vary? When does the temperature of a body exposed to heat cease to rise? Demonstrate the law of cooling, and apply it in the case of radiation from the human body in winter.

ISOTHERMS AND ISOTHERMAL SURFACES.

Isothermal Lines.—If at any time the temperature of the air were observed over the whole surface of the earth, and the temperatures taken were recorded on a globe or map of the world, each in its proper place, there would result a series of places in both the northern and the southern hemisphere at which the temperature would be 70° Fahr. Lines connecting these points would coincide roughly with parallels of latitude. Between these two lines, in a belt covering the equatorial regions, the temperatures would be above 70°, while for points nearer the poles the temperatures would be lower. A line connecting a series of places whose mean temperature is the same is called an *isotherm*, or line of equal temperature.

The position of isothermal lines is continually changing. If a thermometer which now reads 70° should in a few hours read 80°, it would show that the isotherm of 70° had moved to a higher latitude. It often happens that when it is growing warmer in New York, it is growing colder in Ohio, and *vice versa.* At points on the earth where day is dawning, these lines are generally moving away from the equatorial regions; while 180° distant, where evening is coming on, the lines are moving toward the equator. These general movements are modified by storms and air-currents, so that the lines are continually shifting to and fro in a very irregular manner.

Isothermal Surfaces.—Suppose the temperature of the air at the earth's surface is found to be 70° at some station. If the thermometer is carried up into the air, from this station, it will generally show a colder temperature. At the height of 1,000 feet, it would have to be moved toward the equator in order to register again a temperature of 70°. If we suppose the thermometer to continue to ascend, while at the same time moving southward in order that a temperature of 70° may be maintained, we imply that it ultimately reaches the equator. If the southward direction is still continued, it will be necessary to approach the surface of the earth in order to maintain a constant temperature of 70°, and we shall finally reach it at the southern isotherm of 70°.

A thermometer might thus be carried from any point on the northern isotherm due south, in some such path as that described, and finally reach the southern isotherm, indicating at all points on the route a temperature of 70°.

If the journey were conducted a few feet below the surface of the earth, the temperature would fall; but, toward the equator, we should find the soil warmer. A subterranean path connecting the two isotherms might be found, where the temperature is 70°. This path would lie near the surface, but somewhat deeper at the equator than at higher latitudes.

Clearly, then, we have here an isothermal surface, surrounding the earth at its equatorial region, and having a shape somewhat like that often given to a finger-ring (Fig. 155). This surface is continually fluctuated into irregular billows, by clouds, storms, and currents of air. The isothermal lines drawn in physical geographies are the lines in

which isothermal surfaces intersect the surface of the earth. (See Appletons' Physical Geography, pages 66, 67.)

Isothermal Surfaces within the Earth.—If we should start with a thermometer at the surface of the earth, within the equatorial ring of 70°, and carry it downward a few inches or feet into the soil, the temperature would fall, perhaps to 70°. While descending through twenty or thirty feet, the temperature would continue to fall, but thereafter it would rise, as we approach the hot interior of the earth.

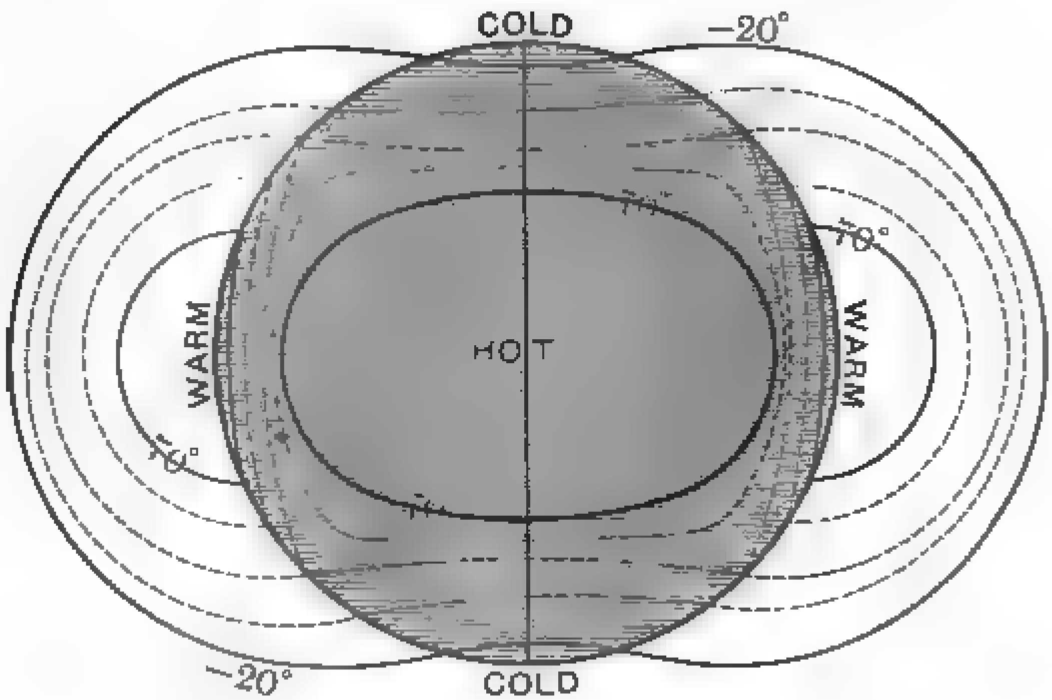


FIG. 155.—ISOTHERMAL SURFACES.

At a depth of perhaps 800 feet, the temperature would have risen to 70° again. Here we are on another isotherm of 70°, surrounding the interior hot core of the earth. This surface is probably wholly within the earth, excepting where it may be carried up by a hot spring or volcano. Within this isotherm will be others, having higher temperatures.

Isotherm of −20° Fahr.—In the equatorial region of the earth, a temperature of −20° would never occur, either at or below the earth's surface. In the arctic regions, the air falls far below this temperature. If we bore into the

earth there, it will in general grow warmer as we go down, until a temperature of —20° is reached. At lower depths, the temperature will be higher. If we follow the isotherm of — 20° southward, it will finally come to the surface, then rise into the air, and envelop the equatorial regions of the earth at a point far above the isotherm of 70°. To the southward, the isotherm of —20° again dips to the earth, and holds a part of the antarctic land, like that of the arctic region, in its cup-shaped basin. It could, however, never enter unfrozen water (why?), but would in arctic seas lie within the ice, or in the air very close to the water.

Frequently in winter the isotherm of —20° dips to the earth in a local down-pour of cold air in the latitude of Chicago, and even occasionally as far south as St. Louis.

In Fig. 155, the isotherms are drawn as if the arctic regions were occupied by land; but of course they are not drawn to proper scale. Other isotherms between those of —20° and 70° are shown, and it is left to the reader to understand them without further explanation.

It will be seen that every isothermal surface in and around the earth, including all artificial sources of heat, is a completely closed surface, and surrounds a region where the temperature is either warmer or colder than it is on that surface.

APPLICATION OF HEAT IN THE PRODUCTION OF WORK.

Heat-Engines.—Heat is extensively utilized to save man labor. A heat-engine is a machine in which heat is transformed into mechanical energy, and is thus enabled to perform work by means of the expansive force of steam, hot air, or exploding gas. The expansive force of powder when ignited in a gun-barrel imparts motion to the bullet —hence a gun is a simple heat-engine.

The oldest heat-engine known is described in the "Pneumatics" o Hero, a Greek philosopher who experimented at Alexandria about 15 B. C. It consisted of a vessel of water, A B, closed securely by a li and communicating through the tube on the right with a hollow ba

above. Opposite was a pivot resting on the lid, and the ball was provided with two jets, bent at right angles near their outer edges, as shown in Fig. 156. As soon as heat was applied to the vessel, steam entered the ball and issued violently from the mouth of each jet, causing the ball to revolve. Hero's was a simple rotary engine.

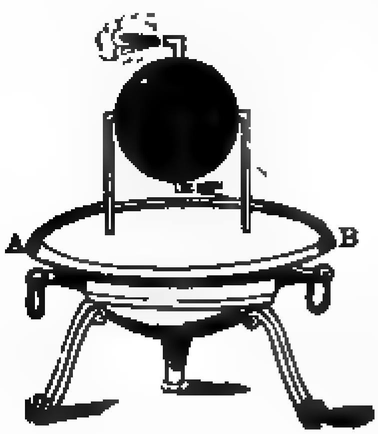


FIG. 156.—HERO'S STEAM-ENGINE.

Little attention was given to the development of the heat-engine from the time of Hero until the seventeenth century. The study of the application of steam was then resumed, and successive improvements have been made in steam motors by various investigators until the present perfection has been attained.

The Modern Steam-Engine utilizes the pressure of steam for doing work. The steam is generated in a boiler, B (see Fig. 158), and is conveyed to a cylinder, C, through a steam-chest, S. The steam-chest contains a valve, V, which

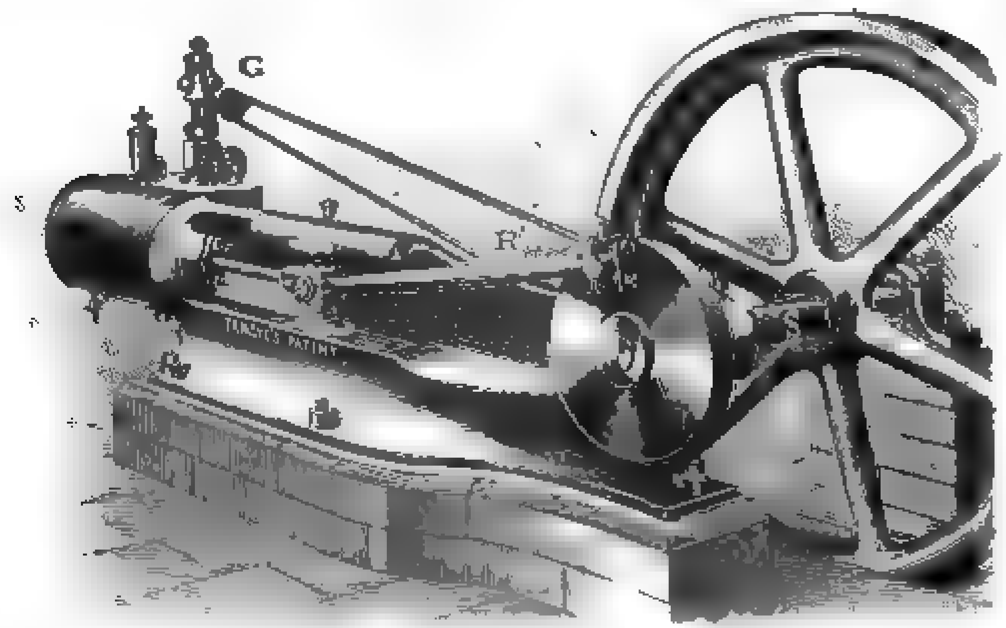


FIG. 157. MODERN STEAM-ENGINE.

is moved to and fro by the rod A, admitting steam first at one end of the cylinder and then at the other. The press-

ure of the steam is thus applied alternately on opposite sides of the piston, driving it to and fro. The power is transmitted through the piston-rod R to the driving-shaft, as shown in Fig. 157.

The piston-rod terminates in a cross-head moving between guides, thus securing a straight-line motion. The cross-head is connected with the crank-pin upon the balanced disk of the main shaft by the connecting-rod R (see Fig. 157). The valve-rod, A (see Fig. 158), is driven to and fro by power derived from the main shaft, as is shown in Fig. 157, where S represents the main shaft.

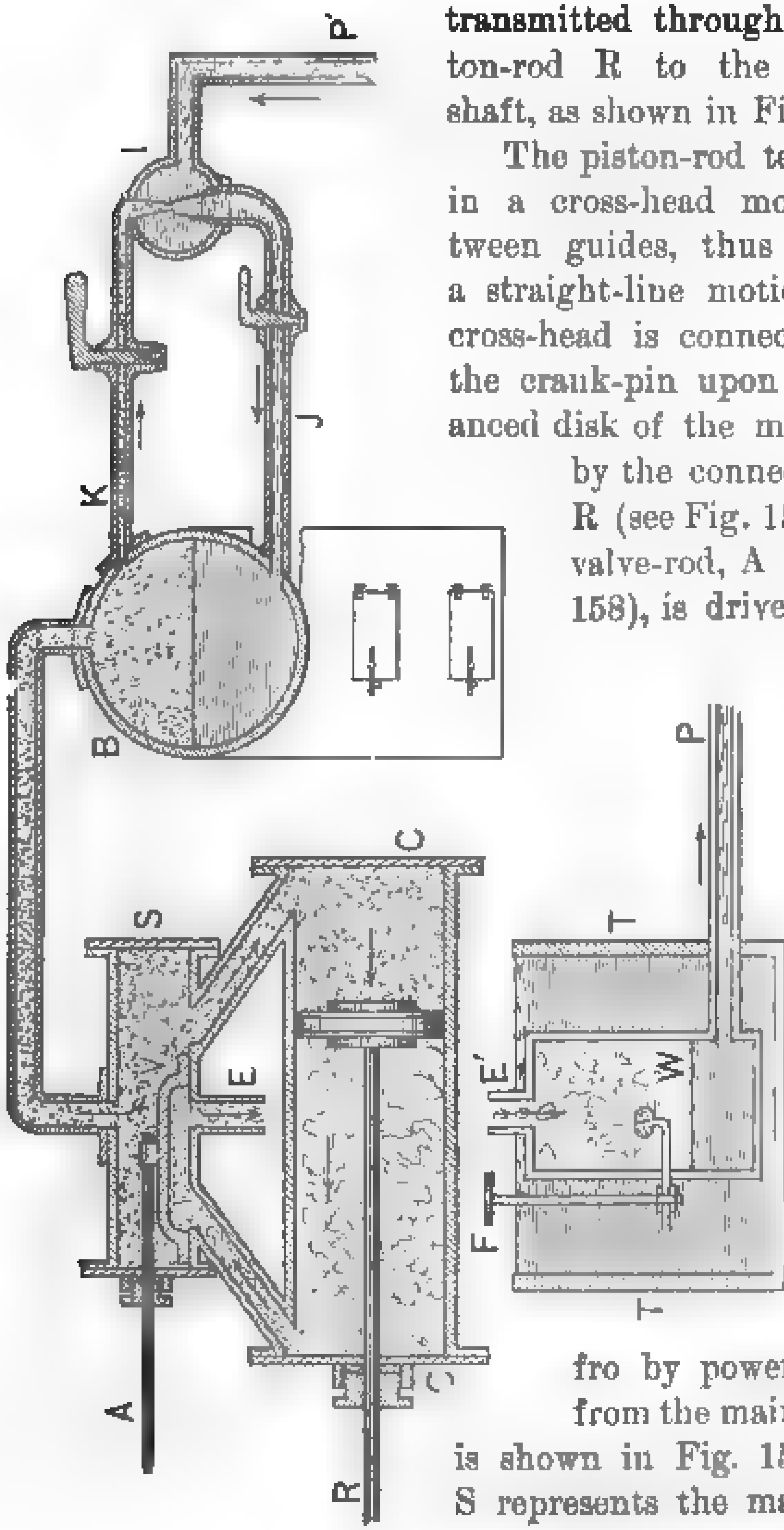


FIG. 158.—DIAGRAMMATIC SECTION OF MODERN STEAM-ENGINE.

A circular disk, *e*, is eccentrically mounted upon the shaft and can be rigidly connected in any desired position by a set screw. Surrounding the eccentric is a collar, within which the eccentric turns when the shaft is revolved.

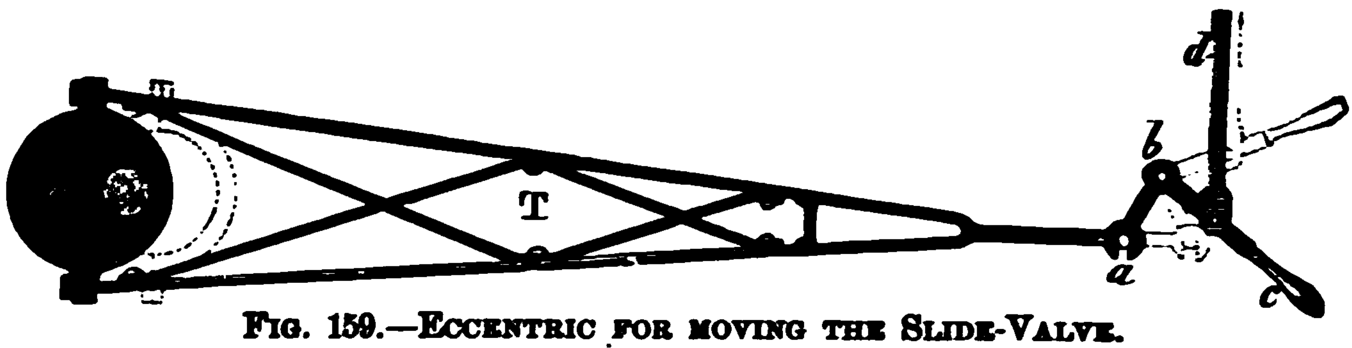


FIG. 159.—ECCENTRIC FOR MOVING THE SLIDE-VALVE.

The other end, *a*, of the eccentric frame being connected with the valve-rod, it is evident that the valve will slide to and fro with every revolution of the shaft.

At each stroke, the steam on the driven side of the piston is put in communication with the air and is swept out through the exhaust-pipe E (Fig. 158). As here shown, the steam is entering the head end of the cylinder, and the crank end is connected with the exhaust-pipe E. The student should make a drawing showing the position of the valve on the return-stroke, when these connections are reversed.

In some engines, the exhaust-pipe E connects with a condenser shown in the lower part of Fig. 158. The exhaust-pipe would be connected at E′, leading the steam into a chamber, W, surrounded with water contained in a tank, T. Water is pumped into this tank and escapes by a waste-pipe. This water condenses the steam. At the same time an air-pump connected with the pipe P pumps air, water, or steam, from the condenser, delivering the water to a tank called the "hot well." The water required to supply the boiler is taken from the hot well by a force-pump or an injector.

The effectiveness of the condenser is vastly increased by admitting water from the tank T into the condenser through a short pipe terminating in a bulb, or "rose," with fine holes for spraying the condensing steam. This supply is regulated by a valve controlled at F. As the pressure in the condenser is considerably below that of the atmosphere, the water will flow in if this valve is opened.

Engines which exhaust their steam directly into the air are called Non-condensing Engines. The back pressure on the exhaust side of the piston is never less than the atmospheric pressure.

In condensing engines, the back pressure is that of the condenser. This pressure will depend upon the temperature of the condensing water and the effectiveness of the air-pump. If the water entering the condenser contained no air, the pressure would be determined wholly by the temperature of the water. If this temperature were 60° Fahr., the pressure in the condenser would be about half an inch of mercury (according to the table, page 257, it would be 0·518 inch) or $\frac{1}{60}$ atmosphere. The pressure in the condenser is usually about $\frac{1}{10}$ atmosphere.

In large stationary engines, and particularly where water is cheap, the condenser is an advantage. For the same boiler pressure, the effective pressure on the piston is increased by about $\frac{9}{10}$ atmosphere, as the back pressure is diminished by that amount.

The Injector.—The feed-water from the hot well is forced into the boiler by a pump, and it is common to use an injector also.

The principle of the injector may be understood from Fig. 160. A glass tube, A B, of about half an inch diameter, has within it a tube which fits rather closely and is sealed in position with sealing-wax. The inner tube is at one point drawn down to a diameter of about $\frac{1}{16}$ inch. The outer tube simply serves to protect the inner one from breaking at its narrow part. Force water through the tube from a hydrant. A break will be observed in the water column just after it passes the narrow part; it will appear like snow-white foam. At the same time a rattling sound will be heard like that made when a jet of steam is discharged under water.

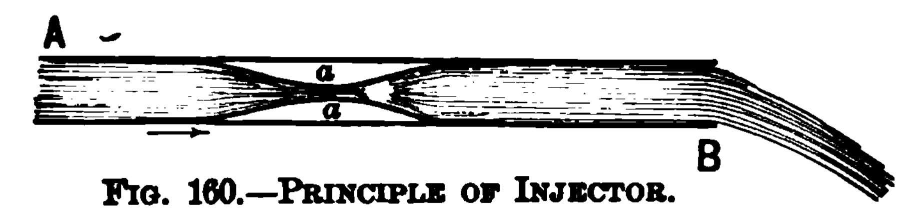


FIG. 160.—PRINCIPLE OF INJECTOR.

If the section of the tube at *a a* is $\frac{1}{10}$ of the section at the wide part, the velocity of the water-particles at the small section will be ten times as great as at the wide part, since the same amount of water passes through one section as the other in each second. The moving energy of a particle at the narrow part will therefore be 100 times as great as a moment later when it has reached the wider part. Just at the place where the tube widens, the water ceases to fill it if the hydrant pressure is sufficient. The swiftly moving particles in minute

spherules shoot across the vacuum formed and bombard the more slowly moving mass in front, producing the sound heard and maintaining the width of the gap in the water column.

The feed-water injector is a similar device. One form of it is shown at I (Fig. 158). Steam from the boiler passes through the tube K and escapes through a small cone-shaped nozzle into a slightly wider nozzle upon the feed-pipe J. The pipe J leads back to the boiler below the water-line. The two nozzles are inclosed by a pipe, P′, which dips into the feed-water in the hot well. The steam rushes through the narrow opening, condensing to water as it passes through the feed-water, which must cover the gap between the two pipes, and goes back into the boiler, carrying the feed-water with it.

The Governor is an ingenious piece of mechanism designed to make the engine run steadily by regulating the admission of steam (see G, Fig. 157). It consists of two heavy iron balls which revolve about a spindle driven by the engine, and which, under the influence of the centrifugal tendency, fly out from the spindle in proportion to the rapidity of revolution. In moving out, they act in a certain manner on the regulator of the engine, which may be a throttle-valve between the engine and the boiler, and cut off the supply of steam. As they fall toward the spindle, the valve is opened and steam again admitted.

Air and Gas Engines include those machines in which the working element is air or some gaseous product of combustion. A piston may be driven with great velocity by the elastic force of heated air, or by the expansion of a mixture of gas and air at the moment of explosion. Otto's silent gas-engine is operated on the latter principle, a dilute mixture of coal-gas and air being ignited in the cylinder under a pressure of three atmospheres. A governor regulates the admission of the gas. Gas-engines possess an advantage not only in being easily made ready for use, but also in the limited amount of fuel consumed.

The Naphtha-Engine.—The vapor of deodorized naphtha has proved a safe and easily controlled source of power

a motor recently devised. The naphtha is confined in tank. Gas coming from this naphtha is forced through pipe to a burner, where it is ignited and heats a retort or

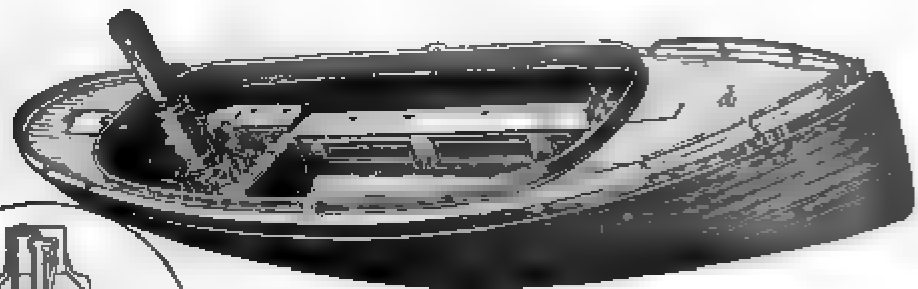
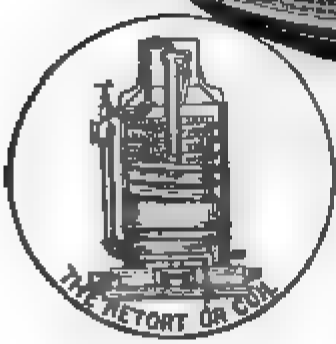


FIG. 161 LAUNCH EQUIPPED WITH NAPHTHA-ENGINE.



coil, prominent in Fig. 160 on top of the engine. When the coil is sufficiently hot, liquid naphtha is forced into it. This at once vaporizes and expands, thus creating pressure on the cylinder, as indicated by a gauge, and this pressure is utilized to move the machinery. As the naphtha-pump is connected by an eccentric with the main shaft, at each revolution of this shaft naphtha is automatically supplied to the boiler. An injector communicating with the retort supplies a portion of the vapor regularly as fuel.

The engine above described is used in the naphtha launches of the Gas-Engine and Power Company, of New York. The machinery occupies little space, and is manageable by a child. There is freedom from the dirt inseparably associated with the use of coal, and the expense of running the engine is small.

QUESTIONS.—Explain isothermal lines. Show how isotherms change their position. How are their general movements modified? If a thermometer be carried upward from a point on the earth's surface, and then moved southward, how may a temperature of 70° be maintained? How, after crossing the equator? What are isothermal surfaces? Are there isothermal surfaces within the earth? Show how this may be. Trace the isotherm of 20° F. Construct a diagram illustrating approximately the isotherms of 20° and 70° F.

What are Heat-engines? Illustrate in the case of a gun barrel. Describe the oldest known heat-engine. The modern steam-engine, reproducing the figure in its essential details. What is the eccentric? the injector? the governor? State the difference between condensing and non-condensing engines. Explain the principle of air and gas engines; of the naphtha-engine.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Sum up the properties of heat you have become acquainted with in the preceding lessons. When is a body hot? When cold? When do bodies feel neither hot nor cold? Sum up the general effects of heat.

The temperature of a school-room in North Dakota was 60° F., while outside, the reading of the thermometer was 52° F. below the freezing-point. Express the difference in degrees Centigrade. Express 0° F. on the Centigrade scale.

The extreme range of temperature at Werchojansk, in Siberia, is 185° F. Express this in degrees Centigrade; in degrees Réaumur. Is this change in temperature as great as the difference between the freezing and boiling points of water?

The temperature of the earth's crust rises about 100° F. for the first mile of descent toward the earth's center. How many feet of descent will involve a rise of 1° C.? How many centimetres? (See table, p. 540.)

Why should the walls of a cellar, if exposed to frost, contain no stones that project into the soil? (*Expansion of water in freezing; principle of lever.*)

Instance an exception to the rule that bodies are contracted by cold.

Why do you run the risk of breaking a tumbler by pouring hot water into it, and why does a silver spoon placed in the tumbler remove the danger?

How many times its volume does water expand when converted into steam at 100° C.? Under a pressure of one atmosphere, how many cubic inches of steam may be generated from two cubic inches of water? If 51,000 cubic feet of steam be condensed, how much water will result?

Suppose six pounds of quicksilver at 100° C. to be mixed with two pounds of iced water, and the temperature of the mixture to be 8·5° C. Find the specific heat of quicksilver.

If five pounds of steam at 100° C. are forced into 32 pounds of water at 15°, what will be the resulting temperature? *Ans.* 99·0°.

If 50 grammes of ice at a temperature of —10° C. are put into 400 grammes of water at a temperature of 80°, the temperature of the mixture will be 61·7°, what is the specific heat of ice? *Ans.* 0·47. Careful experiment shows the specific heat of ice to be 0·489.

How much shorter is a surveyor's steel chain, 100 links in length, at the freezing-point than at summer heat, or 75° F.?

Which is warmer to the touch, a conductor or a non-conductor? On what principle is the shell of a modern breech-loading shot-gun exploded? On what principle was the old flint-lock discharged? Why is glass so perfect a protector of young plants rooted in a hot-bed?

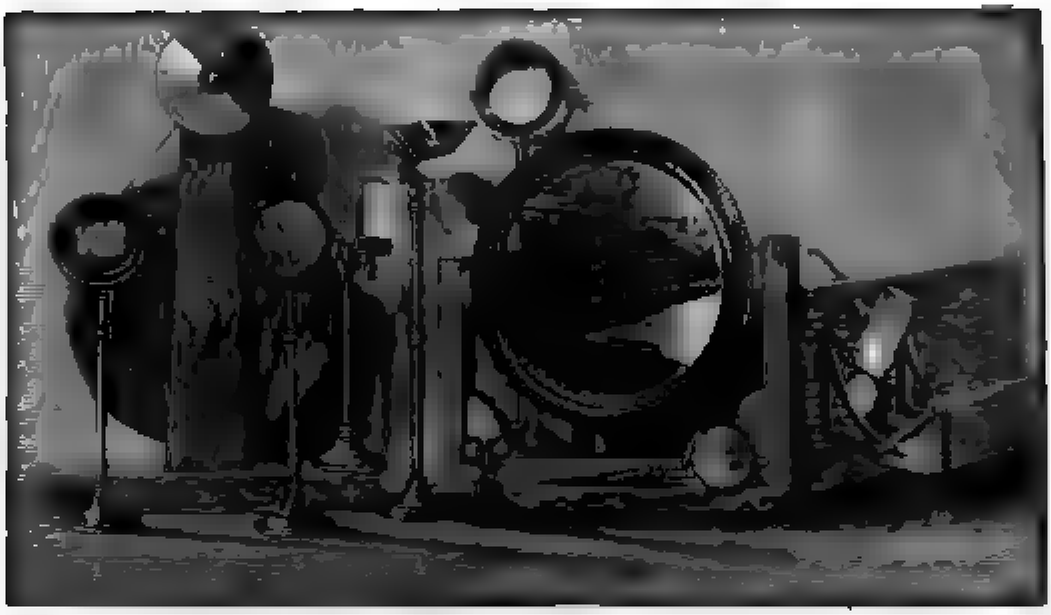
Suppose the reading of the wet bulb of a psychrometer to be 25°, and the temperature to be 29°; find the dew-point.

How does the heat which the hand receives when held six inches from a lighted Duplex burner compare with what it receives at a distance of two feet?

The mean distance of the sun from the earth is 93,000,000 miles; that of the moon is 239,000 miles. If the sun were as near as the moon, about how many times as much heat should we receive from it?

Venus, at times the brilliant evening star, is 67,000,000 miles from the sun; how does its solar heat compare with ours?

The distance from New York to Chicago is 977 miles. Find the difference between the total length of the steel rails connecting these cities, on the hottest day in summer and that on the coldest day of winter, assuming the temperature to vary from 20° below zero to 90° above If the rails are 30 feet in length, what space must be left between the ends?



LIGHT.

PROPERTIES OF BODIES AS REGARDS THE PRODUCTION AND TRANSMISSION OF LIGHT.

Relation between Light and Heat.—All bodies, at all times and at all temperatures, are in a state of molecular agitation whose energy is Heat (see page 37). Some of this energy, their molecules impart, in the form of periodic vibrations, to the ether, which is supposed to pervade all space, both inside and outside bodies, and to exist in the most nearly perfect vacuum which we can produce. The

NOTE.—The following outfit, in part illustrated above, is suggested to the young experimenter: No. 1 represents a combination of *cylindrical* lenses designed to illustrate the correction of astigmatism (see page 349); 2, a Newton's disk and rotator; 3, a double concave lens, mounted; 4 and 5, glass prisms, mounted; 6, a pocket microscope; 7, a plano-convex lens; 8, a convex mirror; 9, a double convex lens or reading-glass; 10, Prof. Mayer's heliostat, described on page 299. The pupil is advised to supply himself with a complete set of six demonstration lenses, unmounted, a Nicol's prism, a concave and a convex mirror, a mirror of black glass, a three-inch prism, and a crystal of Iceland spar. This collection will be furnished by any instrument-dealer at a moderate price. Small concave and convex mirrors and burning-glasses may be purchased at the toy-stores for a few cents. The rotator and heliostat illustrated above are furnished at a moderate cost by Samuel Hawkridge, instrument-maker to the Stevens Institute, Hoboken, N. J.

energy of ether vibration, however, is not heat energy; it is another of the forms described on page 38, and is called Radiant Energy. The process of emitting radiant energy is Radiation.

The ether-vibrations pass off in all directions, by a species of wave-motion, with great velocity. If these waves impinge upon objects, the radiant energy is transformed, producing effects determined by the nature of the body upon which they fall. On the skin, they cause the sensation of warmth; on a thermometer, a rise of temperature—indicating in each case that radiant energy has been turned into heat. But the most remarkable effect is that produced when the radiations strike the eye, and are converted in the mysterious structures of the retina into proper stimuli of the optic nerve fibers. When such radiations are between certain limits of wave-length, these fibers, thus stimulated, become the means of awakening in the brain the sensation which we call Light.

The word Light is commonly used in the sense of **Radiant Energy**; it is thus employed in what follows.

As some air-waves do not excite sound-sensations because they vibrate too quickly or too slowly (see page 399), so there are ether-vibrations which do not affect the optic nerve. When vibrations are properly timed, very striking mechanical and chemical effects may occur. An army of men keeping step on a bridge set it into strong vibration, and may shake it down. In like manner, light-waves falling upon silver salts used in photographic plates, cause a vibration which shakes asunder the particles of which they are composed.

A Luminous Body is one which emits light. When the light originates with the radiating body, the latter is said to be *self-luminous.* The sun, whose surface is composed of exceedingly hot and brilliant clouds, the flame of a candle or a gas-jet, a fire-fly, are self-luminous. Other bodies, like the moon and most of the objects surrounding us, are seen by reflected light, which originates in some self-luminous body. They are said to be *illuminated.*

When light passes through space which is occupied by matter, part of the light is always quenched or extinguished. It is sometimes said to be *absorbed.*

Transparent Bodies absorb very little light. Objects can be seen through them distinctly. A perfectly transparent body would be invisible.

Glass, water, and air are transparent. When glass or ice is pulverized, light is quenched by repeated reflections from the internal faces of particles which present themselves at all possible angles to the rays. Such a mass is said to be *opaque;* it intercepts rays of light and casts a shadow. Snow or crushed ice united into a continuous mass by pressure becomes transparent. A *translucent* body allows some light to pass through, but objects can not be seen through it.

Opaque Bodies become translucent, and even transparent, when in thin layers. The sun may be seen through a thin layer of silver deposited on the object-glass of a telescope, although a less brilliant body would be invisible.

All substances, even those which are transparent, intercept some of the light which they receive. The sun's rays lose much of their brilliancy by passing through the earth's atmosphere. As we ascend above sea-level, less and less light is absorbed, and the heavenly bodies become more distinctly visible.

PROPAGATION AND VELOCITY OF LIGHT.

Light moves in Straight Lines.—When a beam of sunlight is reflected into a darkened room, its path is revealed by illuminated particles of dust. This path is observed to be straight. We see each point of every object by means of the light which it radiates. If light did not travel in a straight line through the sights of a rifle to the eye, it would be impossible accurately to direct the ball.

Images by Small Apertures.—A result of the rectilinear path of light is shown in the formation of images by small apertures. If a minute opening be made in the side of a dark box or chamber, and the light which enters be received on a screen, images of external objects will be seen

in an *inverted* position—that is, the objects will be represented as upside down. These images reproduce the objects in form and color.

The light which passes through the opening from each point of the object falls upon a definite point of the screen and on no other. The image is thus a continuous series of innumerable bright spots. The screen may be at any distance from the opening. The size of the

FIG. 163. FORMATION OF IMAGE BY SMALL APERTURE.

image will be observed to increase, while its brightness diminishes, as this distance increases.

Pierce a sheet of paper with a pin and allow sunlight to pass through the opening and fall upon another sheet of paper. A round image of the sun will be seen. If a second hole be made, there will be two images, which will overlap if the screen be far enough away (Fig. 164). Continue to pierce holes near together. Each one will yield a new image. As the paper wears out and the holes break into one another, the screen shows a luminous patch of light. A window-opening may be supposed to be made up of an infinite number of small openings placed side by side, and the patch of sunlight on the floor to be an infinite number of overlapping images of the sun. A single image would, therefore, be produced only by an extremely small opening. Let the pupil explain why.

The brightness of the image decreases as the opening becomes smaller. The latter may have any shape, if small; but is incapable of producing an image, if large. Images of the sun may often be seen on the floor where sunlight streams through small apertures in the blinds, and on the ground where light shines through the foliage. In a partial eclipse of the sun, these images have been observed to be crescent-shaped. Why? Such images can be photographed by substituting a plate with a small opening for the lenses of an ordinary camera.

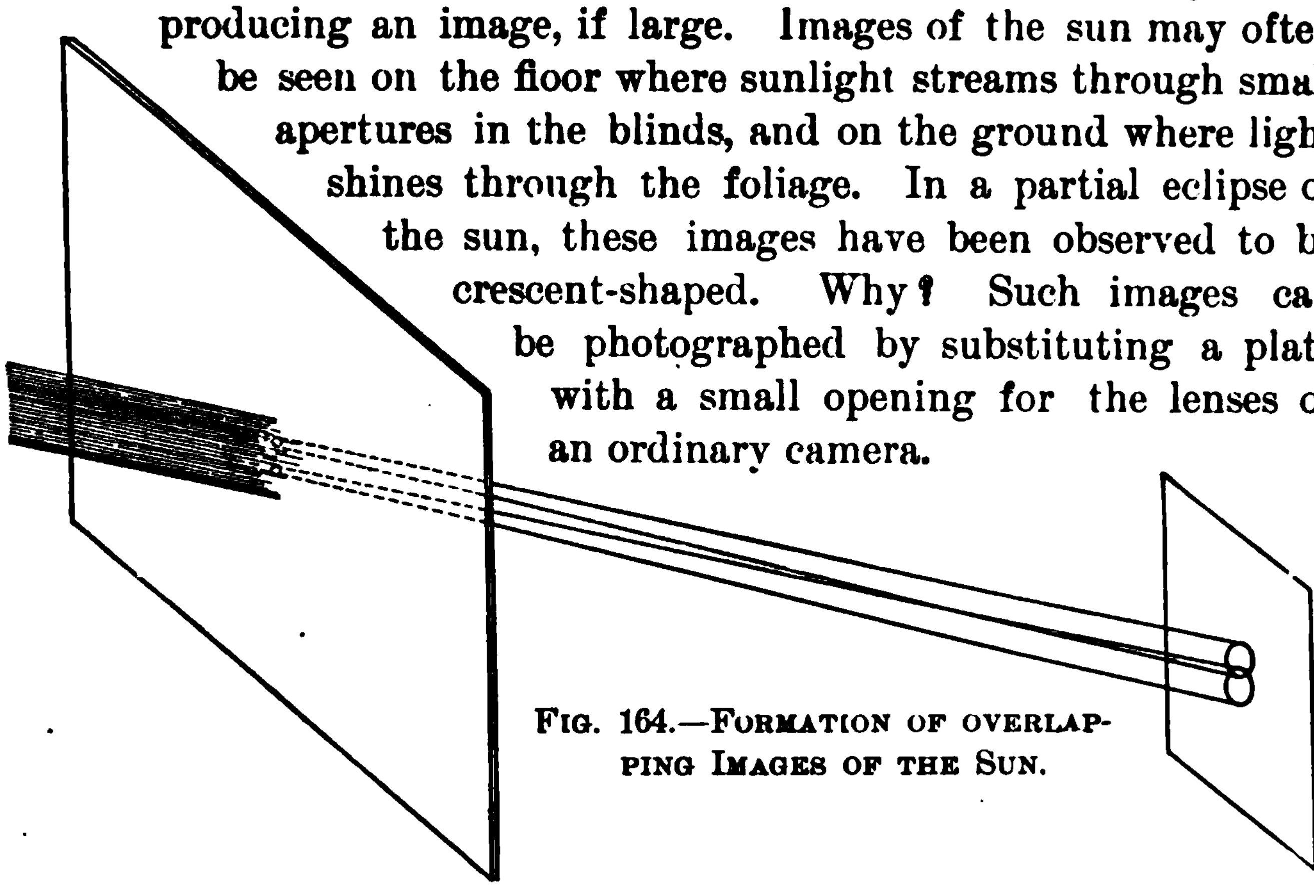


FIG. 164.—FORMATION OF OVERLAPPING IMAGES OF THE SUN.

Velocity of Light.—Light travels in space with a velocity of about 186,000 miles a second. This fact was first determined by Roemer (*rö'mer*), a Danish astronomer, some two hundred years ago. He made observations on the nearest of Jupiter's satellites, which revolves round that planet as the moon does round the earth, and which at regular intervals passes behind or into the shadow of the planet and is eclipsed—that is, becomes invisible to an observer on the earth. (Consult Fig. 165.)

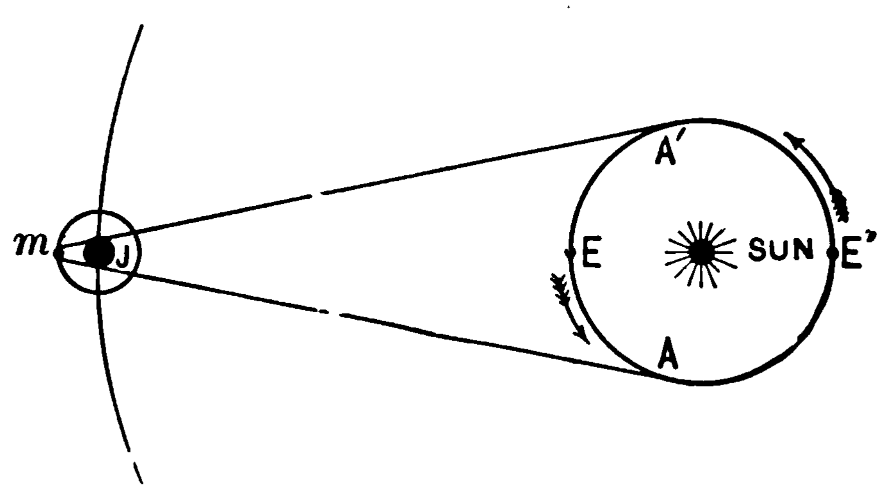


FIG. 165.—ROEMER'S METHOD OF DETERMINING THE VELOCITY OF LIGHT.

Roemer noticed that when the earth is at E, the interval between the invisible periods is 42 hours, 28 minutes, and 36 seconds; but that as the earth moves in its orbit, or pathway round the sun, to A and E', directly away from Jupiter, this interval lengthens. By the time the earth reaches E', the eclipse has fallen behind 16

minutes and 36 seconds. As the revolutions of the satellite take place in exactly the same number of hours, the apparent lengthening of the interval between the eclipses can be explained only on the supposition that light from the satellite *m* occupies time in its passage through space to the earth, and that this time is lengthened by the motion of the earth away from the satellite. In traversing the distance E E′, or twice the distance of the earth from the sun (186,000,000 miles), 16 minutes and 36 seconds are consumed. It was thus an easy matter for Roemer to determine how far light traveled in a single second. How is the apparent interval between successive eclipses affected as the earth moves back again to E?

The velocity of light has been determined by other methods, with closely agreeing results. While one is pronouncing its name, light might travel eight times the distance round our earth. The remoteness of the fixed stars from us may be inferred from the fact that the time required for the passage of light from those that are more distant is estimated at many thousands of years. It thus becomes possible, through the instrumentality of light, in a measure to conceive of the vastness of space.

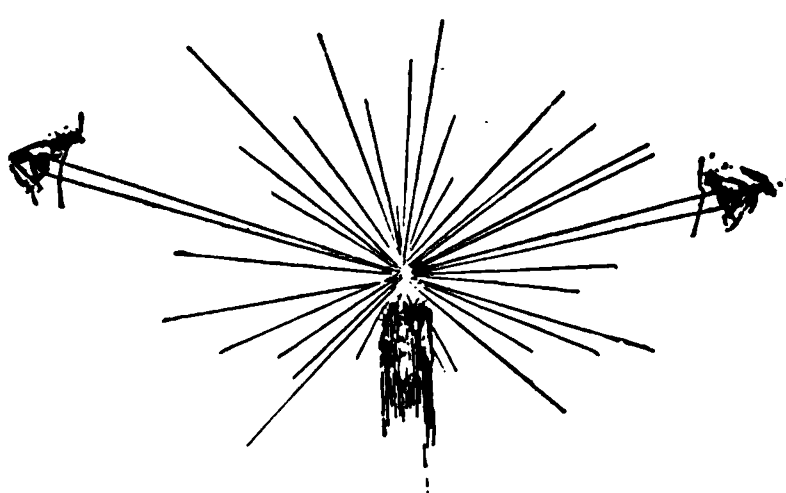


FIG. 166.—CONES OF LIGHT.

Seeing an Object.—Each point of an object sends rays of light in all directions. We see any point by means of a cone of rays whose vertex is at the point and whose base is the pupil of the eye. If we view the object from a different position, we see it by means of a different cone of rays, which, however, have diverged from the radiant-points.

QUESTIONS.—What relation can you discern between Heat and Light? What obvious distinction? What is radiant heat? Do all heat-vibrations affect the optic nerve? Describe the effect of light on silver salts. As regards the production of light, how are bodies divided? Distinguish between self-luminous

and non-luminous bodies. How may non-luminous bodies become visible? Whence does the moon borrow her light? As regards the transmission of light, how are bodies divided? What are transparent bodies? Translucent bodies? Opaque bodies? How may opaque bodies become translucent? Why are the stars more brilliant when viewed from a mountain-top?

Describe the path of light in a uniform medium. How is this path revealed in a dark room? Prove that light travels in straight lines, from what is noticeable in rifle practice; from the lengthening of shadows toward sunset. Explain what is formed on a screen opposite an aperture in the shutter of a dark room. On what does the size of the image depend? On what its brightness? How may images of the sun be formed? What have you often noticed on the ground when walking through a grove on a sunny day?

What is the velocity of light? By whom was it determined? State the facts and reasoning by which the astronomer arrived at his conclusion. How long does it take the light of some of the stars to reach us? If the course of light was not rectilinear, how long would it be in flashing around our globe? The wild pigeon flies with a velocity of 100 miles an hour. If this rate of speed were maintained, how much time would the bird consume in making the circuit of the earth? Why can every person in a large audience see a speaker at the same moment? Does all light travel with the same velocity? ***It does.***

REFLECTION OF LIGHT.—IMAGES BY REFLECTION.

Reflection of Light.—We have learned that light moves in straight lines and is radiated from luminous bodies equally in all directions. When the radiations or rays of light strike a polished surface, they are reflected and take a different direction. If a small opening be made in the

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NOTE.—In order readily to obtain a stationary horizontal beam of light for examination, Prof. Mayer has devised a simple form of the instrument known as the he′liostat (*sun-placer*) Fig. 167. It consists of a piece of board made of a size to fit the window selected for the experiments, pierced with a hole 5 inches in diameter to admit light to the darkened room. Iron brackets (C) 14 inches apart support a shelf 6¼ inches wide, on the outside edge of which a board (D) 7 inches high is screwed, parallel to the large board and 16 inches from it. On the shelf is placed a mirror (O) 6 inches square, standing at an angle and facing the opening into the room. A beam of light is thrown upon this mirror from a second mirror above in such a manner that it is reflected through the opening horizontally into the darkened apartment. The upper mirror (6 × 10 inches) is movable, so that it can be adjusted to the movement of the sun in the heavens.

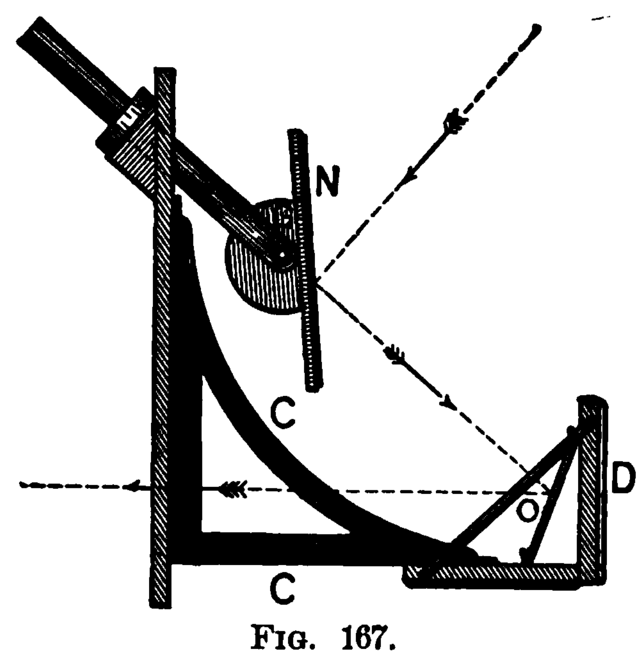

FIG. 167.

shutter at S, sunlight entering with a velocity of 186,000 miles a second and striking a mirror (M), seems to rebound. S M is called the *incident ray*, and M S′ the *reflected ray.*

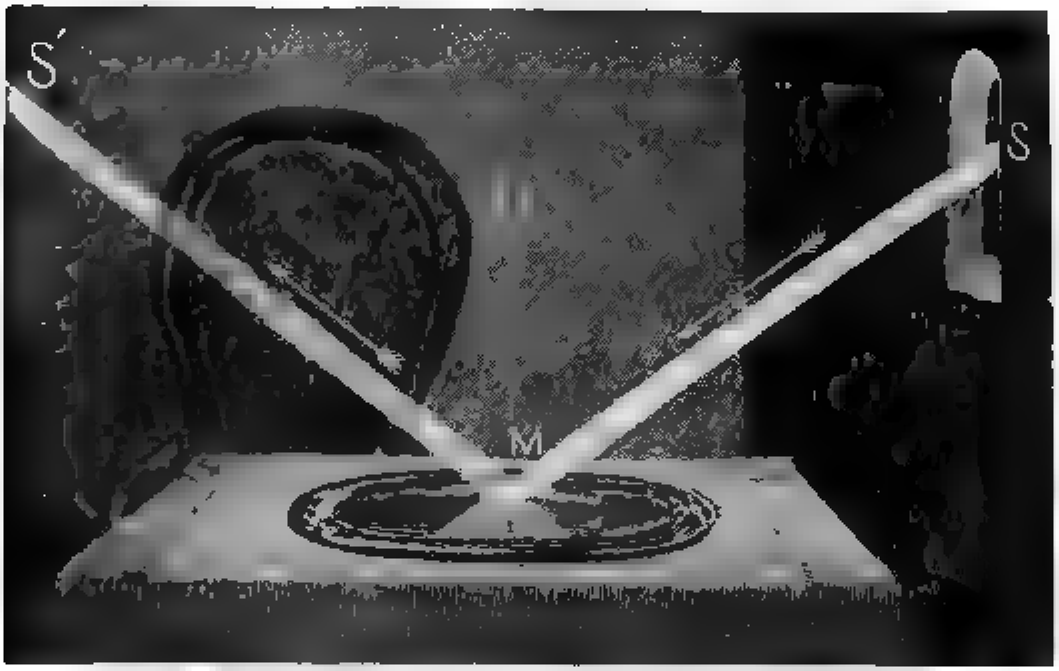

FIG. 168. ILLUSTRATING THE REFLECTION OF LIGHT.

The point M is called the point of incidence, and a line N M, perpendicular to the mirror at that point, is called *the normal* at M. The angle S M N is called the angle of incidence, and the angle S′ M N the angle of reflection.

It is fastened on a board (N), to the back of which is tightly screwed a half-round flat piece of wood (G). This circular piece plays in a slot cut in a round length of hard wood, being fastened to the overlapping ends of the handle by an ordinary iron bolt and nut. A hole 1¼ inches in diameter is now cut in the window-board and the handle fitted therein, as shown in the cut. Arrange the mirrors so that a round beam of light will enter the room, and turn the handle of the instrument, as necessary, to keep the beam in place. The size of the beam may be regulated by placing a piece of cardboard over the aperture, pierced as desired. In the heliostat of the instrument-makers, the sunbeam is kept in a fixed position by the action of clock-work. (*See Mayer & Barnard's "Light," page* 16.)

With Prof. Mayer's apparatus (which any one familiar with the use of carpenter's tools can easily construct), and the few lenses, prisms, and mirrors, shown on page 293, the young pupil may perform for himself a series of simple and instructive experiments illustrating the phenomena of light. A slender beam of light may be admitted with the aid of the heliostat, and leisurely studied. A hand-mirror may be used to reflect it, and it may be thrown wherever desired; or, if reflected from a small piece of looking-glass fastened over the wrist with warm wax, it will respond amusingly, on the wall or ceiling, to the pulse-beats.

Laws of Reflection.—The angles of incidence and reflection are equal.

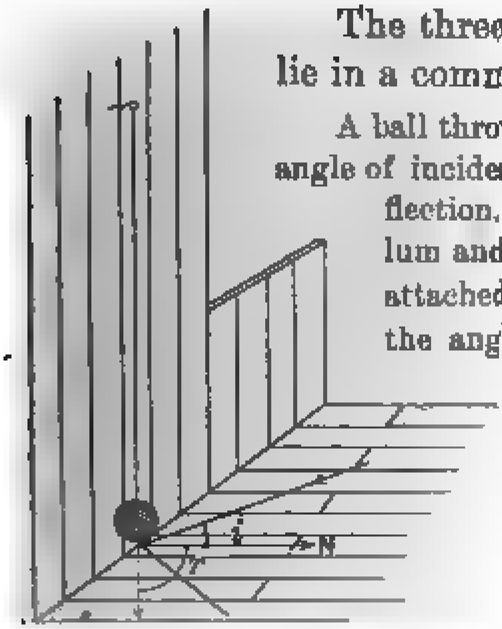

FIG. 169.—ANGLES OF INCIDENCE AND REFLECTION.

The three lines bounding these two angles lie in a common plane.

A ball thrown against a wall will rebound, but the angle of incidence is always less than the angle of reflection. A base-ball, suspended like a pendulum and striking against a wall to which it is attached (Fig. 169), will rebound very little, and the angle *r* will be much larger than *i*. If a more elastic ball be taken, the angles will be more nearly equal. Evidently the ball and wall must be perfectly elastic in order to make the angles *r* and *i* equal. If, therefore, the reflection of light involves the rebound of elastic particles, as was formerly thought, they must be so nearly perfectly elastic that no difference between the angles *i* and *r* can be detected.

Images by Plane Mirrors.—Images are formed by mirrors in accordance with the laws of reflection. Any radiant point O, in front of a plane mirror, will radiate light in all directions. Part of the rays will strike the mirror and will be reflected according to the law already given, the angles *i* and *r* being equal.

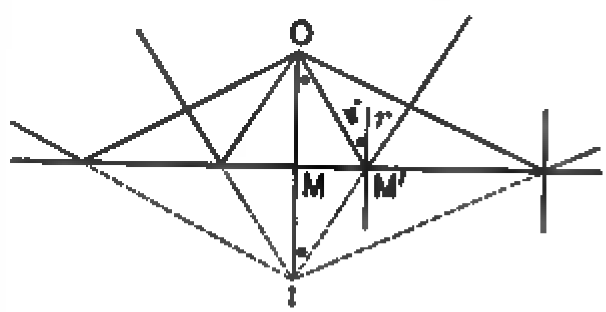

FIG. 170.—IMAGE BY PLANE MIRROR.

Draw the normal at any point of incidence M'. Draw also a normal through O, producing it through the mirror. Produce the reflected ray through the mirror, until it intersects the normal O M in I. The angles marked (.) are all equal by elementary geometry, and O M = I M.

The points O and I are thus on opposite sides of the mirror, upon a common normal. They are also at equal distances from the mirror.

All reflected rays produced through the mirror will intersect in the same point I. An eye so placed that the reflected rays can enter it, will see the same appearance at I as at O, the point from which the rays have really come. I is called the image of the point O. We commonly say that we see the image at I, but we are really looking at the point O, by means of rays which, but for the mirror, would not have entered the eye. We are really the subjects of an illusion as regards the position of the object which we see.

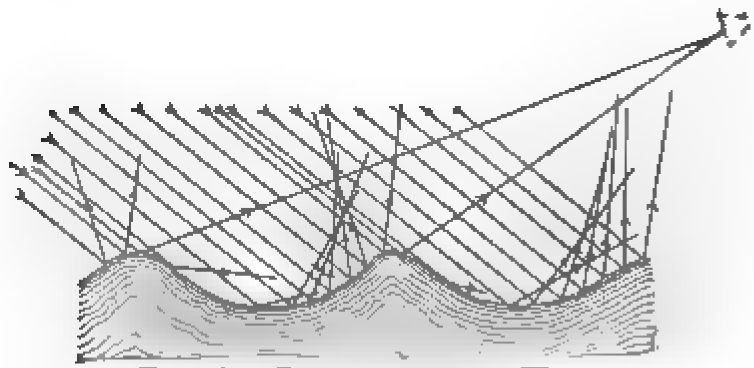

FIG. 171.—REFLECTION FROM WATER.

The reflection of the sun from water often appears as a broad, illuminated patch of light. This is due to the fact that ripples or waves over a wide area present inclined surfaces, so situated that they

FIG. 172.—BRIDGE OVER THE IOWA RIVER, AT IOWA CITY. (VERTICAL DISPERSION, DUE TO RIPPLES, OBLITERATES HORIZONTAL LINES IN THE REFLECTION.)

reflect light to the eye. The rougher the water, the broader this illuminated area will be. Fig. 171 illustrates the reflection of sunlight from a wave surface. The reflection of a bridge from ruffled water often shows an obliteration of all horizontal beams or arches, because

of the dispersion of the images. The images of vertical rods are elongated and indistinct at the ends only. This is due to the motion of the waves, which causes the reflected light to vibrate to and fro, as will be understood from an inspection of Fig. 171.

Reversal of Images.—If you place before a mirror your right hand grasping a pencil, the image will show a pencil in the left hand. This proves that an image in a mirror is reversed as regards right and left, although it looks

FIG. 173.—REVERSAL OF IMAGE IN MIRROR.

like a correct portrait. Every wood-cut and type-face must be made in a reversed position. When held before a mirror, its image shows as a print from it will appear.

Law of Least Time.—If a person were to run from a point A to a point D (see Fig. 174), over uniform ground, upon which he could move with a constant velocity, the journey could be made in the least time if the path were the straight line from A to D.

If he were required to run from A to the wall B C, and then back to D, the journey would be made in the least time if the point m, where he is reflected from the wall, were so chosen that the two lines A m and m D would make equal angles with the wall. They also make equal angles with the normal at m. The distance A m D is shorter than the distance A m'' D, or the distance A m''' D.

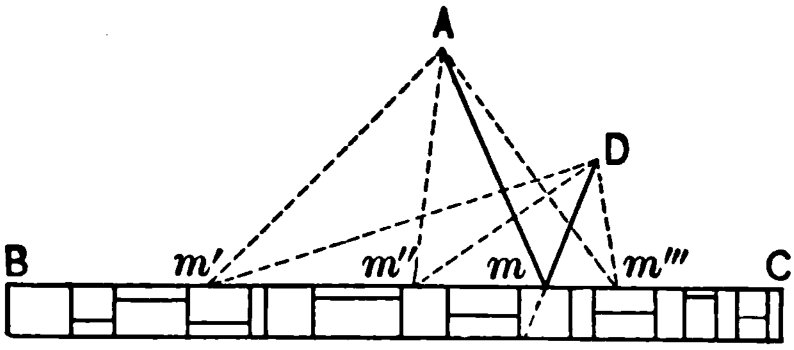

FIG. 174.—PATH AND TIME OF TRANSMISSION COMPARED.

In like manner, light which passes from A to D, after reflection from a mirror B C, traverses the path which makes the time of transmission a minimum.

Images formed by Two Mirrors.—If a lighted candle be placed between two mirrors which face each other, the light will be reflected from one mirror to the other, each reflection giving rise to an image, which is an image of an image in the opposite mirror.

If the mirrors are exactly parallel, the images will be on a common normal, and there will be an infinite number of them at regularly increasing distances from the mirrors. As some light is lost at each reflection, the images decrease in brightness as they recede.

In Fig. 175, 1 is the primary image of O in mirror A, 2 is an image of 1 in mirror B, 3 is an image of 2 in mirror A, etc.

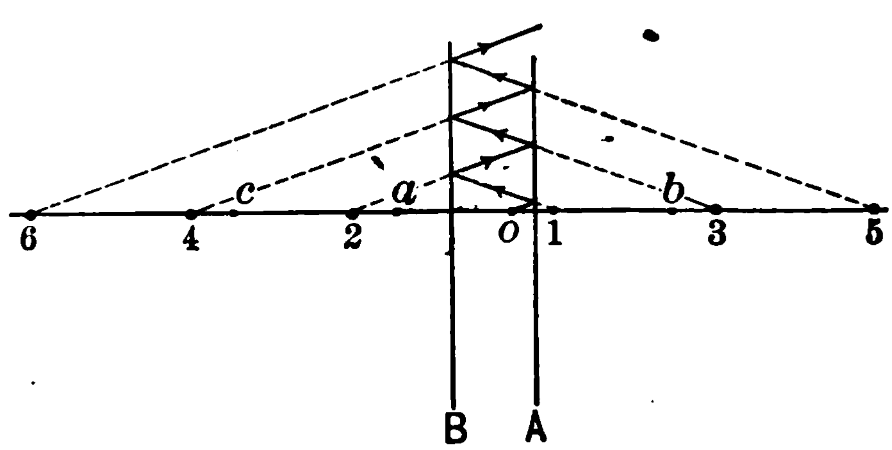

FIG. 175.—MULTIPLICATION OF IMAGES BY PARALLEL MIRRORS.

Use the hand and a printed page as objects, and notice the reversal of consecutive images. The observer may station himself behind one of the mirrors, and look through a pin-hole scratched in its back.

If the mirrors, instead of being parallel, are placed so as to form an angle with each other, the images are limited in number. This principle is applied in the kaleidoscope (*ka-li'do-scope*), a tube com-

monly containing three mirrors set at angles of 60°. Pieces of colored glass, free to move at one end of the tube, are seen through an eye-hole opposite, multiplied by repeated reflections.

Curved Mirrors.—The curved mirrors commonly used as lamp-reflectors are spherical—they are portions of the surface of a sphere.

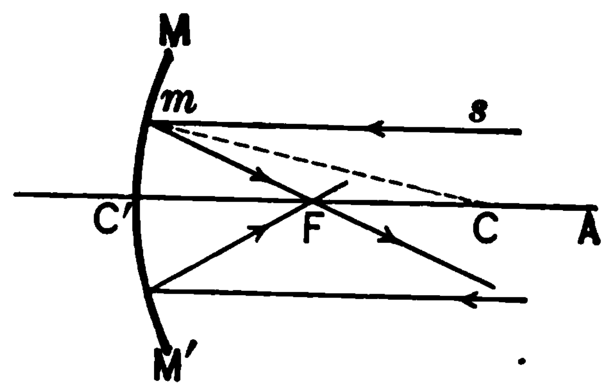

FIG. 176.—CONVERGENCE OF RAYS BY CONCAVE MIRROR.

Spherical mirrors may be either *concave* or *convex*. Fig. 176 is a concave mirror, represented by M C′ M′. C is the center of the sphere of which the mirror is a part. C′ is the center of the mirror, and a right line through C C′ is called the *principal axis* of the mirror.

Rays parallel to the principal axis, striking the mirror as at *m*, converge to a point F, called the *principal focus*.

If rays strike in a similar manner upon the convex side, as in Fig. 177, they diverge, after reflection, as if they had come from the same point F.

The concave mirror converges the light to a focus, the distance of which from the mirror increases as the mirror becomes more nearly plane. The focus of a plane mirror is at an infinite distance. The convex mirror diverges the light as if it came from a point on the opposite side of the mirror, the distance of which also increases as the mirror becomes more nearly plane.

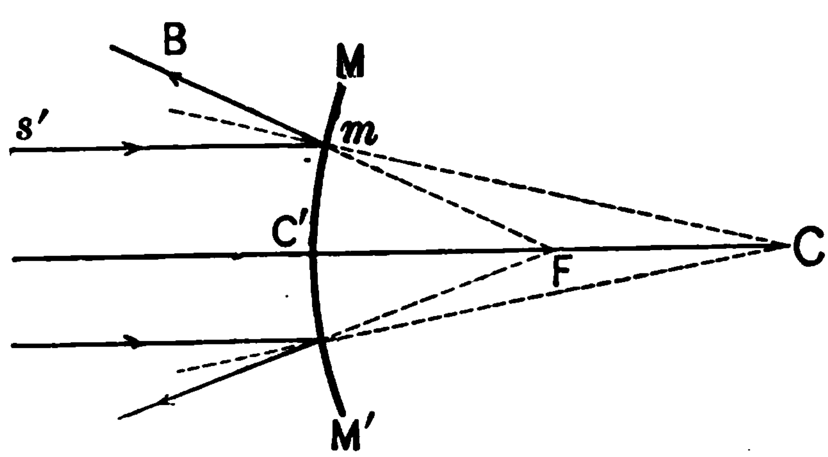

FIG. 177.—DIVERGENCE OF RAYS BY CONVEX MIRROR.

Position of Images formed by Concave Mirrors.—When light from a radiant-point at an infinite distance falls upon a concave mirror, the incident rays will be parallel, and will converge, after reflection, to the principal focus F.

If sunlight falls upon a concave mirror, a small image of

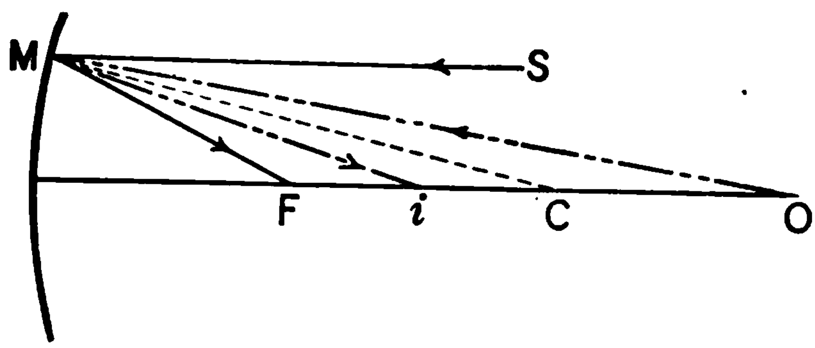

FIG. 178.—POSITION OF IMAGES BY CONCAVE MIRROR.

the sun will be formed at F, and can be seen if projected upon a bit of paper.

Let S M (Fig. 178) be such a ray. If the radiant-point move up to any position O, the angle of incidence at M will be less than before. It will be O M C instead of S M C. The angle of reflection will also be less, since it is always equal to the angle of incidence. The reflected ray will be M *i* instead of M F.

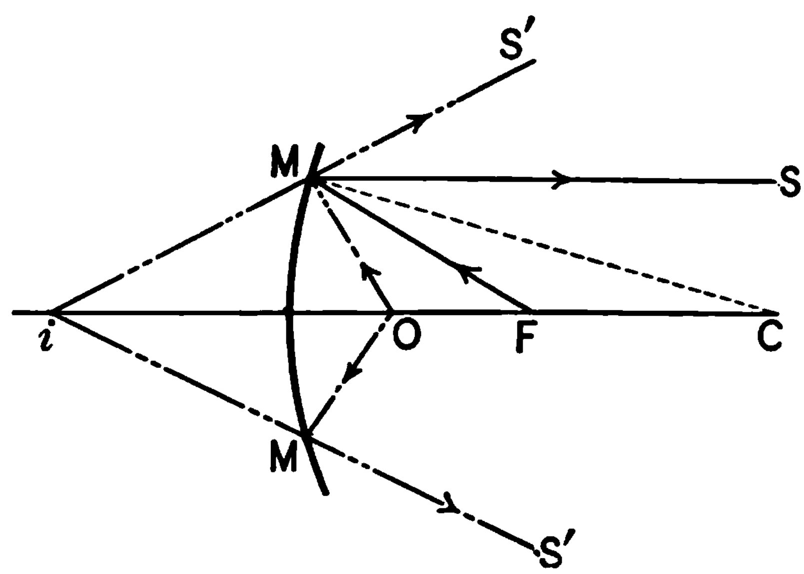

FIG. 179.—POSITION OF IMAGES BY CONCAVE MIRROR.

Rays diverging from O and falling upon the mirror will converge to a point *i*. Thus, while the object has moved from an infinite distance to the point O, the image will move only from F to *i*.

If O moves on up to the center of curvature C, the rays from O will strike the mirror at right angles, and will return on their paths, forming an image by intersection at the same point C.

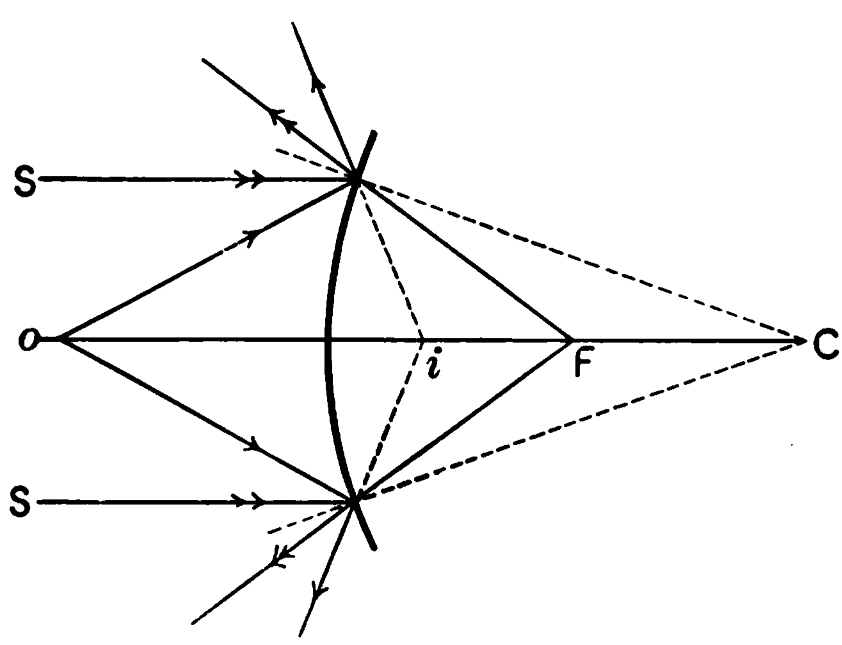

FIG. 180.—POSITION OF IMAGES BY CONVEX MIRROR.

The image and object coincide. If O moves from C to F, the image will move from C to an infinite distance. The emergent rays will be parallel. The incident ray will be F M (Fig. 179), and the reflected ray will be M S.

If O moves from F toward the center of the mirror, the rays will begin to diverge after reflection, as M S′ (Fig. 179). They will form no image on the concave

side of the mirror, but will seem to have come from a point *i* on the opposite side.

As O moves from F to the mirror, the image will move from an infinite distance on the convex side up to the mirror.

If O is on the convex side, the rays will always diverge after reflection (Fig. 180). The object O moving from the mirror to an infinite distance on the convex side, the image *i* moves from the mirror to F.

The Object and Image at Conjugate Points.—In any position, the object and image may change places. If the object be placed where the image is, the image will be formed where the object was. This usually involves a reversal of the direction in which the light travels. A ray of light traversing any path, with any number of reflections, will if reversed retrace that path.

On account of this mutual relation between them, such points are called conjugate (*yoked* or *united in pairs*).

Real and Virtual Images.—When all the rays of light diverging from any point of an object are by any means converged again at any other point, we have a *real* image of the radiant-point. When the rays from the radiant-point are so changed that they seem to have diverged from some other point in space, a *virtual* image is produced.

The images formed by plane and convex mirrors are virtual, as are also those formed by concave mirrors when the radiant-point is between the principal focus and the mirror.

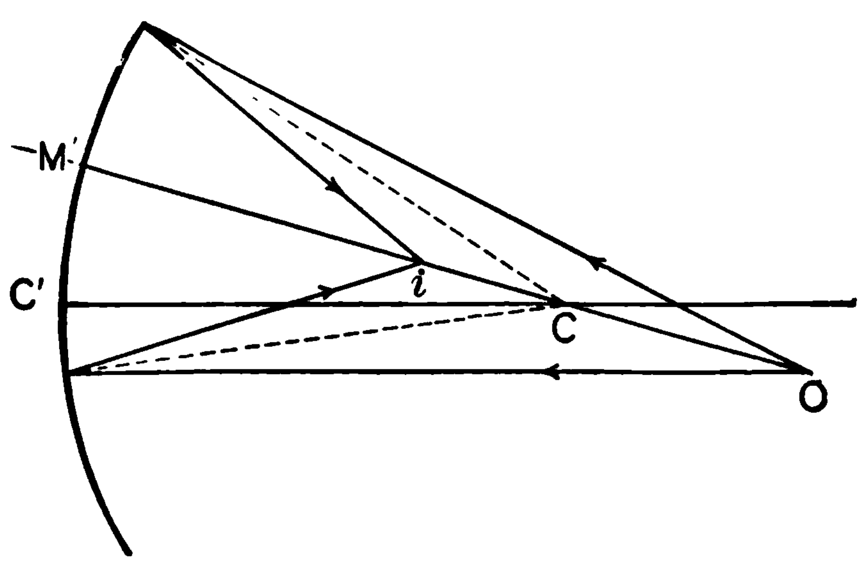

FIG. 181.—SECONDARY AXIS OF CONCAVE MIRROR.

Secondary Axis of a Mirror.—If the radiant-point is not on the primary axis of the mirror, a line may be drawn through that point and the center of curvature, C, which will intersect the mirror in some point M′ (see Fig. 181).

This line is called a secondary axis. It has the same properties as a primary axis, and, like the primary axis, it intersects the mirror at right angles, so that a ray O M′ will be reflected directly back upon itself.

Rays parallel to this axis will, after reflection, converge to a focus at a point midway between M′ and C. The image of the point O will be at a point *i* on the same secondary axis, and its position is determined as before explained (page 305). O and *i* are on opposite sides of the principal axis.

Image of any Object.—In order to construct the image of any object, it is only necessary to locate the images of its extremities, or other principal points. This can be done by drawing secondary axes through those points.

In Fig. 182, the image *a b* of the object A B is constructed. The points A and *a* lie on the same secondary axis. To determine where, on that axis, the image *a* is, draw any other ray from A to the mirror and then find the reflected ray by construction, making the angles of incidence and reflection equal. The image sought will be somewhere on this ray, evidently at its intersection with the secondary axis. In this case, the image *a b* will be larger than the object.

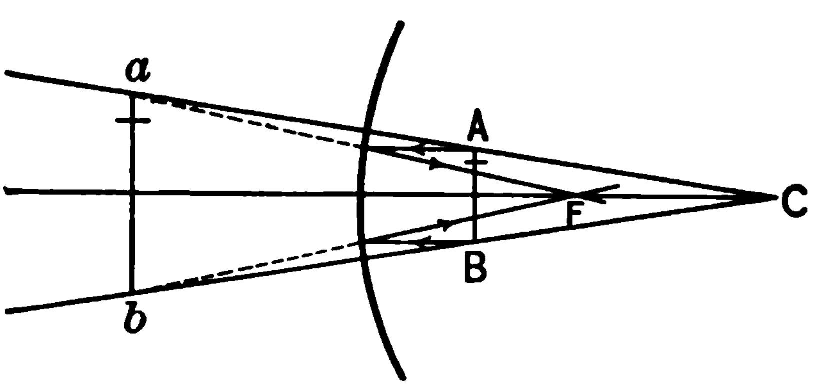

FIG. 182.—MAGNIFIED IMAGE IN CONCAVE MIRROR.

If you hold a concave mirror in your hand and look into it, you will see a magnified virtual image of your face. In like manner, if you should construct the image of an object placed directly in front of a convex mirror, you will understand why such mirrors give a diminished image; but it must be remembered that an object at a distance from a concave mirror produces an inverted and reduced real image. This you can readily prove by standing near a window with a concave mirror in your hand, and casting the image formed of outside objects on a screen held just in front of the principal focus of the mirror. Can you construct a diagram to prove that this must be so?

The Ophthalmoscope, an instrument used by physicians for examining the interior of the eye, is a mirror with

a small aperture in the center. The mirror reflects light into the patient's eye, and the examiner makes his observations through the opening from behind.

Magic Mirrors.—The face of the ordinary Japanese mirror is slightly, though not uniformly, convex. This mirror consists of a thin disk of polished metal, ornamented in relief on the back. The portions of the mirror in front of the relief work become *plane* or nearly so in the process of manufacture, and hence reflect rays that are less divergent than those reflected from the parts that remain convex. If a bright beam of light be reflected from such a mirror, which is partly convex and partly plane, a more or less well-defined image of the raised ornaments on the back will appear on the screen. Mirrors possessing this physical peculiarity are called Magic Mirrors.

Note the advantage of Prof. Mayer's heliostat in experimenting with mirrors. It enables you to follow satisfactorily the course of a single ray.

QUESTIONS.—Describe the phenomena of reflection. How may a horizontal beam of light be obtained for study? Describe Prof. Mayer's heliostat, and state its uses. Can you turn the ray of light from its course? State the laws of reflection. What are rays called that strike a body? Rays that are thrown back? What can you say of the relative reflecting power of dull and polished surfaces? Why is a room with white walls lighter than one papered with a dark pattern? Can you tell why window-panes sometimes appear fiery red at sunset?

What is a Mirror? On what principle do we see ourselves in a mirror? How far behind a plane mirror does the image of an object appear? How many kinds of mirrors are there as regards shape? What relative position do the image and object occupy as regards the normal? Show when they are equally distant from the mirror. Show how we are deceived in regard to the position of an object seen in a mirror. Describe and explain the common appearance of the reflection of the sun from waves. Why is there an obliteration of horizontal features in the reflection of a bridge from ruffled water? Explain the reversal of images in mirrors. State the law of least time, and apply it to light. Describe the formation of images by two parallel mirrors; by mirrors placed at an angle. What is the kaleidoscope?

What are curved mirrors? Define the principal axis and focus. On what does the distance of the focus depend? How far from a plane mirror is its focus? Describe the reflection from a concave mirror. Discuss the relation between the positions of the object and the image when the former is beyond, at, and within the center of curvature. Where must the object be to have the rays di-

verge after reflection? What are conjugate points? Distinguish between real and virtual images. What is the secondary axis of a mirror? Describe images of objects placed directly in front of concave mirrors; of convex mirrors; at a distance from concave mirrors. What are magic mirrors?

REFRACTION OF LIGHT.

Refraction illustrated.—Construct a rectangular box having one side of glass fastened by means of wooden strips laid in white lead. Throw a slender beam of light S (see Fig. 183), directed into the room by means of the heliostat, over the edge of the box and along the glass side. Note the point A where it falls upon the bottom. Fill the box with water, and cloud the water slightly with a few drops of an alcoholic solution of mastic. The beam of light will now bend at the water surface, and will proceed to a point B.

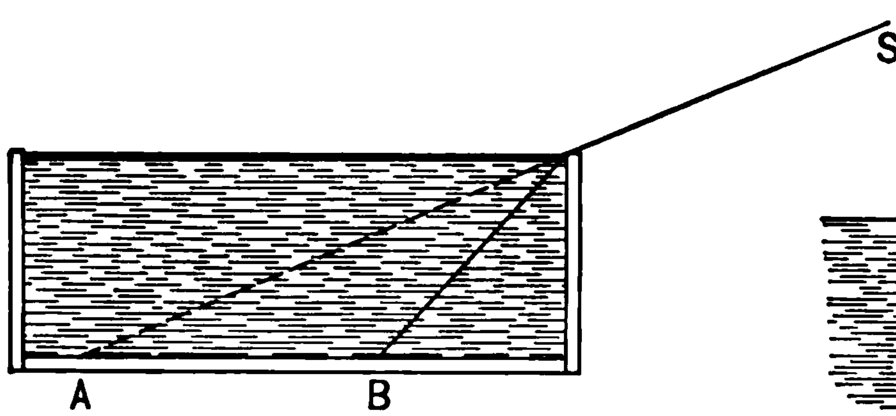

FIG. 183.—REFRACTION OF A BEAM OF LIGHT IN WATER.

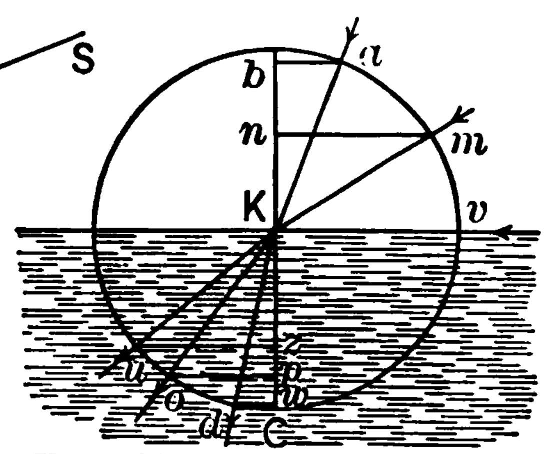

FIG. 184.—ILLUSTRATING THE LAW OF REFRACTION.

The path of the beam within the water will be a straight line, but it is bent downward, or *refracted*, from the water surface.

Law of Refraction.—To explain the law of refraction, draw a circle having a radius of one unit, say an inch, foot, or decimetre, and having its center in the water surface at the point of incidence K, as in Fig. 184. The incident ray may be represented by a K, and a K b is the angle of incidence. Then the line $a\ b$ is called the sine of the angle of incidence. This is abbreviated *sin i.*

In the water, the ray takes the direction K d. This line

represents the refracted ray; C K d is the angle of refraction, and $d\,w$ is the sine of the angle of refraction, which is abbreviated *sin r*.

It is found by careful measurements that when i changes, r always changes in such a way that *sin i* is always $\frac{4}{3}$ of *sin r* when light passes from air into water. If m K is the incident ray, then K o will be the refracted ray, where $\frac{a\,b}{d\,w} = \frac{m\,n}{o\,p} = \frac{4}{3} = \frac{\sin i}{\sin r}$.

This constant ratio between the sines of the angles of incidence and refraction is called the Index of Refraction.

If the ray enters the water along the line b K, it will proceed in the same straight line.

If the ray enters sensibly parallel to the surface, as in the case of v K, the angle of incidence is 90°, and the sine of $i = 1$, or v K. The refracted ray will pass along a line K u, so located that $u\,z$, or the sine of $r = \frac{3}{4}$ of K v, which is the sine of the angle b K v.

Strictly, the light can not enter parallel to the surface, but it may be directed into a globe half full of water. If the light enters at u, and is incident at K, it will pass out along the surface in the direction K v. Similarly, the light may be sent through the water along the lines o K or d K, when it will pass into the air along the lines K m and K a.

Values of the Index of Refraction.—The bending of the ray at the bounding surface between two media is different for different media.

When light passes from air to water, the index of refraction is $\frac{4}{3}$; from air to glass, it is $\frac{3}{2}$; and from water to glass, it is $\frac{9}{8}$.

Phenomena of Refraction.—A stick partly immersed in water appears bent, unless it stands vertically, when it appears shortened.

The rod A D B (Fig. 185) is bent into the form A D B′ when viewed from e. The plumb-bob w will seem to be at w', which is directly above w. The plumb-line appears straight throughout, but the part below the water appears shortened.

The appearance of the rod may be found as follows: From e draw $e\,o$ or $e\,o'$, producing the lines indefinitely below the surface $o'\,o$ D. With o and o' as centers, draw circles, each having a unit radius. Then the lines $s\,s$ are the sines of the angles of incidence, and the refracted rays $o'\,s'$ and $o\,s'$ must be so drawn that $s'\,s'$ is $\frac{3}{4}$ of $s\,s$.

Light radiated from B through o' will reach the eye at e. The light will seem to have come from B'. The point B of the stick will seem to be at B', which is directly above B.

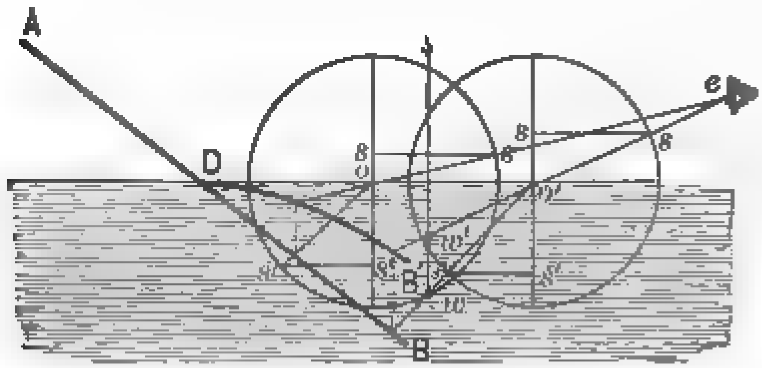

FIG. 185.—PHENOMENA OF REFRACTION.

The rays from an object below the water are not brought to a sharp focus, so that such objects seem indistinct, particularly for large angles of incidence. It is on account of refraction that one must aim below the apparent position of fish in shooting or spearing them. Here, as in reflection of light, the eye always refers the direction of a body along the direction which the light from it has on entering the eye.

Apparent Depth of Water.—If one stand in a pool of clear water, the depth of which is everywhere the same, the bottom will appear dished. The water will seem deepest just below the eye. A few feet distant, water four or five feet deep may seem not over a foot in depth. If, however, the bottom seems flat, the water would grow deeper as one went outward from the eye. Many persons are drowned by reason of these deceptive appearances.

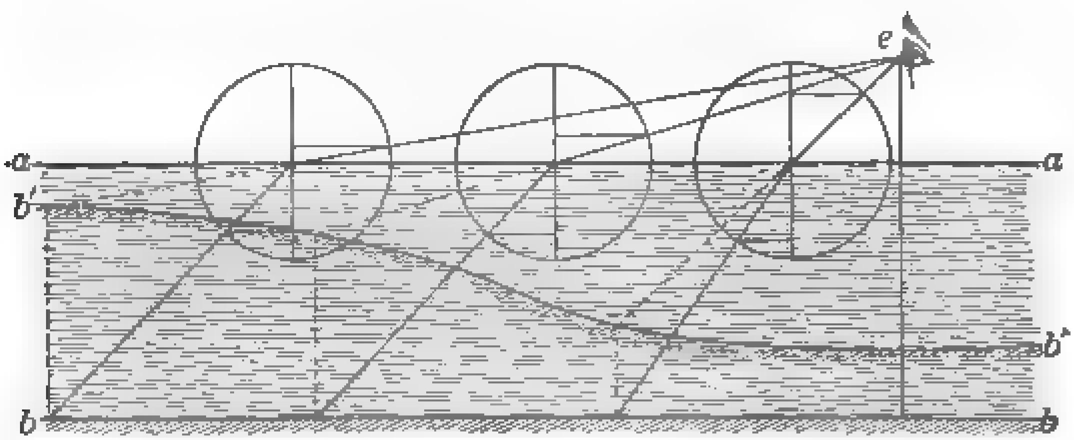

FIG 186.—SHOWING THE APPARENT SHOALING OF UNIFORMLY DEEP WATER.

The phenomena just described are noticeable in a tank 12 or 14 inches long and 8 to 10 inches deep, if it be filled with clear water, and

the eye be placed near the water surface. Let *a a* (Fig. 186) be the water surface, and *b b* the bottom, *e* being the position of the eye. Then will *b′ b′* be the appearance of the bottom.

Draw lines from the eye to any points in the surface. At these points erect normals, draw circles of unit radius around them. The position of the ray in the water can then be found as before described. Produce this ray to the bottom *b b*. The point thus determined will seem raised vertically to the prolongation of the ray passing through *e*.

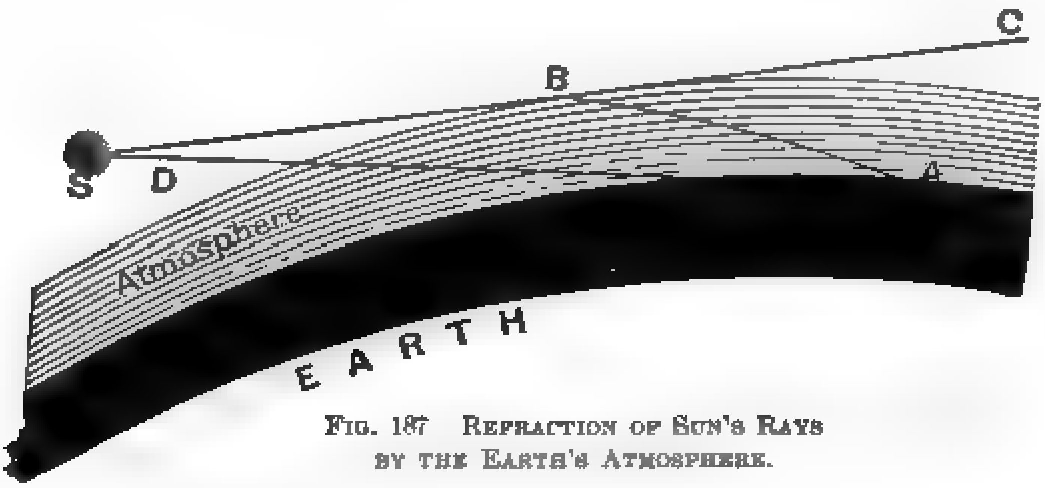

FIG. 187 REFRACTION OF SUN'S RAYS BY THE EARTH'S ATMOSPHERE.

An inspection of Fig. 187 will make it clear that we see the sun both before it rises and after it sets. Suppose the observer to be stationed at A. Rays from the sun, like S D, would not reach A at all, because the round earth is in the way; but rays like S C, passing through air of increasing degrees of density, are repeatedly bent toward the normal, until they reach the earth's surface at A.

If the refractive power of air be subjected to constant modification, as by the warm currents rising from a hot stove, objects viewed through it will appear to have a wavy or tremulous motion.

Total Reflection.—Light striking the water at any angle between 0° and 90°, will enter and suffer refraction, as explained. In Fig. 188, the paths of rays 1 *m* 1, 2 *m* 2, 3 *m* 3, and 4 *m* 4, are shown. When the angle in the air is 90°, or *z m* S′, the sine of the angle of incidence is the radius, and *v w*, which is ¾ of the radius, will be the sine of *r*, or *v m n*. If the light were to be reversed in direction, each ray would retrace its entire path. If the incident ray were to sweep through the angle *n m v*, being always inci-

dent at *m*, the ray emerging into the air would sweep through the angle *z m* S′.

If the ray were incident at *m*, but should lie within the angle *v m S*, it could not pass through the surface into the air, but would be wholly reflected into the water, making the angle of incidence equal to the angle of reflection. Under these circumstances, a water-air surface is a perfect reflector of light.

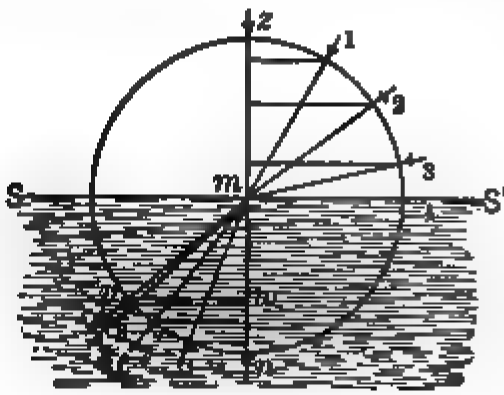

FIG. 188.—ILLUSTRATING THE CRITICAL ANGLE.

The angle *v m n* is called the *critical angle*. If the incident angle in water is greater than the critical angle, total reflection takes place.

The phenomena of total reflection may be shown by means of a glass cube, such as is commonly used as a paper-weight (see Fig. 189).

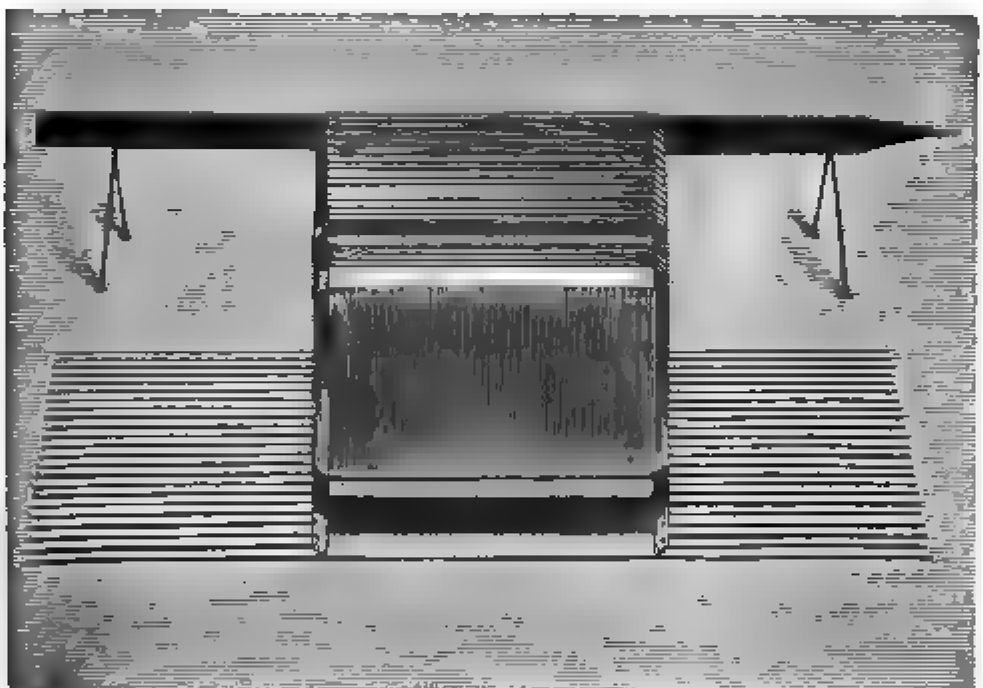

FIG. 189.—TOTAL REFLECTION IN THE CASE OF GLASS PAPER-WEIGHT.

Set the cube down on a band of ruled lines of exactly the same width as itself. The lines below the cube are invisible through the

side faces. The bottom presents a silvery appearance, like a mirror, and seems to be much narrower than the band of lines. The lead pencil shown in the figure is also invisible through the top face, by reason of total reflection from that face; but it is seen reflected from the bottom face.

In the top face, two sets of ruled lines are visible. The lower lines are seen directly through the bottom of the cube, their apparent position being changed by refraction. The upper lines are also the lines below the cube, seen by total reflection from the back face. These two sets of lines are separated by the beveled edge of the cube.

Allow a film of water to creep under the cube. The lines below the cube can then be seen through the sides, if the eye be somewhat raised; but on depressing the eye, the lines disappear and the silvery appearance of total reflection is observed. The critical angle of glass in contact with water differs from that of glass in contact with air.

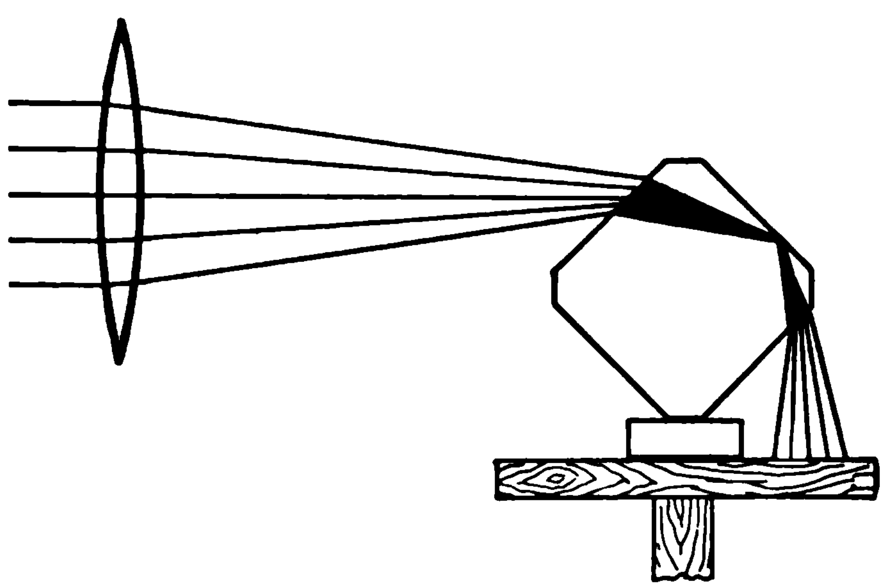

FIG. 190.—TOTAL REFLECTION BY GLASS CUBE.

The cube may be placed on edge and a beam of light (from a lens of long focus, or directed by the heliostat) sent into one face so as to strike an adjacent face from the inside. Total reflection of the beam will be seen, its track being revealed by a greenish color (see Fig. 190).

Light under Water.—Light radiating from a point O (see Fig. 191) below the surface of water, as in the case of a submerged electric globe, will pass out into the air, following the laws of refraction. All rays from O, making an angle with the normal equal to the critical angle, will pass out in the surface of the water. These rays are marked O C, and constitute a cone whose vertex is at O. Rays striking the water farther out, and making an angle of incidence greater than the critical angle, would be totally reflected.

An eye placed at O, would see within the cone C O C, all objects above the water surface. The sun just rising would be seen by means

of the ray S C, which would seem to have come from C′ C. The whole water surface outside of the points C would appear lifted to form a cone C′ C C C″. A boat at *a* would seem to be at *a′*, a bird at *b* at *b′*, while a fish at *f* would be seen at *f′*, by total reflection.

These appearances can be experienced by sinking quietly below smooth clear water, and looking out through the surface. If one is

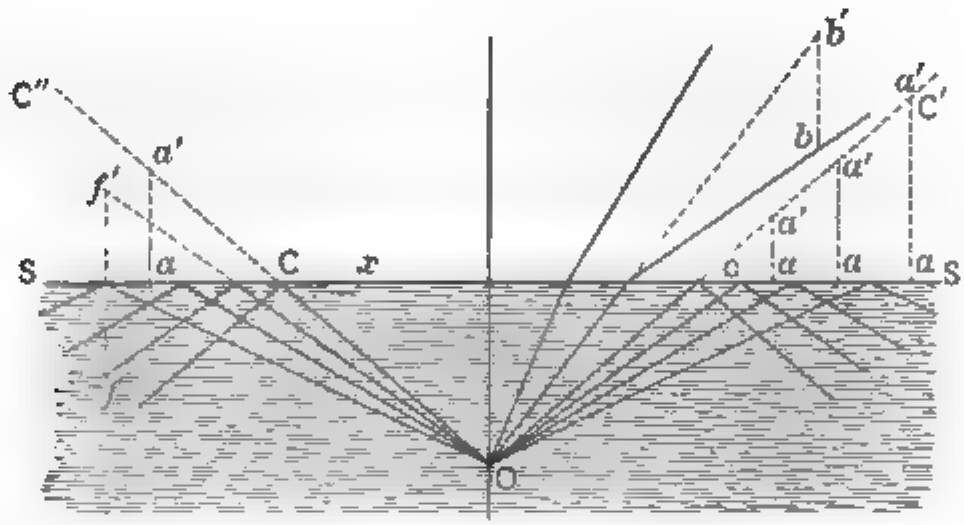

FIG. 191.—PHENOMENA OF REFRACTION AND REFLECTION FROM A POINT OF VIEW BENEATH THE WATER.

provided with a rather large rubber tube through which to breathe, they may be studied more at leisure.

The shooting-fish of Java is said to project drops of water from its prolonged snout so as to bring down insects flying near the surface. The fish must then be able to allow for the difference between the real and the apparent position of its prey.

Look at the diagram and state where an artificial fly on the surface at *x* would appear to a fish at *f*; to a fish at O. Could an angler on the bank occupy any position where he would be out of sight of a fish in mid stream?

Value of the Critical Angle.—The critical angle is the angle which the ray makes with the normal in any more refracting medium, when the corresponding angle in the less refracting medium becomes 90°.

As in all cases $\frac{\sin i}{\sin r}$ = index of refraction, if i represents the angle in the more refracting medium, then for water-air—

$$\frac{\sin i}{\sin r} = \frac{\sin c}{\sin 90} = \frac{\sin c}{1} = \frac{3}{4}.$$

That is, when $r = 90°$, i becomes c or the critical angle. This angle is one whose sine is $\frac{3}{4}$ the radius. Similarly for glass-air, the sine of the critical angle is $\frac{2}{3}$, and for glass-water the sine c is $\frac{8}{9}$. By construction and measurement by means of a protractor, these angles can be found approximately. They can also be obtained by consulting a table of natural sines:

Substances.	Index of refraction.	*sin c.*	c = critical angle.
$\frac{\text{water}}{\text{air}}$	$\frac{3}{4}$	$\frac{3}{4}$	48° 35′
$\frac{\text{glass}}{\text{air}}$	$\frac{2}{3}$	$\frac{2}{3}$	41° 48′
$\frac{\text{glass}}{\text{water}}$	$\frac{8}{9}$	$\frac{8}{9}$	62° 44′

The index of refraction from water to air is $\frac{3}{4}$, and from air to water it is $\frac{4}{3}$. The substance containing the lesser angle (water) is said to be more refracting than the substance containing the greater angle.

The diamond is a highly refractive stone; hence its luster. Certain rays falling on the internal surfaces of the facets are, also, totally reflected. The diamond's index of refraction being about $\frac{12}{5}$, while that of glass is only $\frac{3}{2}$, we are furnished with a certain test by which to detect imitation stones.

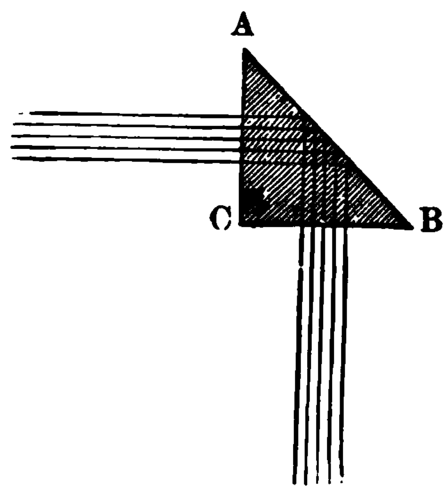

FIG. 192.—TOTALLY REFLECTING PRISM.

Applications of Total Reflection.—The glass prism of 90° is frequently used as a reflector. It is more effective than an ordinary mirror, since all the light is reflected.

Light striking the face A C at right angles passes on without deviation to the diagonal face A B. The angle of incidence there is 45°, which is greater than the critical angle 41° 48′. No light, therefore, can pass through the face A B. It is all reflected.

The Camera Lucida.—The principle of total reflection is utilized in the Camera Lu'cida, an instrument designed to facilitate the drawing of distant objects. Rays strike the face *c d* of a totally reflecting prism, inclined at

an angle of 22½°. (See Fig. 193.) They are totally reflected to the surface *d a*, and thence to the eye *p p*. As the paper and pencil to be used in the sketch are not visible through the prism, the eye must be so placed that a part of the pupil projects beyond the prism. Half of the pupil thus receives the reflected rays, and the reflected image is seen projected on the paper beneath. There is a movable piece of brass with a hole in the center, which serves as an eye-piece.

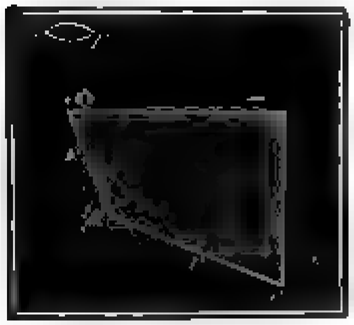

FIG. 193.—SECTION OF PRISM.

The camera lucida is useful, not only for drawing objects, but also for copying. The copy may be reduced to any size by regulating the distance of the original from the prism. You can construct a simple camera lucida by fixing on a stand a piece of plane glass at an angle of 45° to the horizon. An image of surrounding objects will be seen through the glass on a sheet of paper laid on the table. The glass both reflects the image and permits the writing materials to be seen through it, so that an outline may be readily traced. Why is the image in this case inverted?

Prisms like the above are sometimes fixed at the eye-pieces of telescopes. They reflect images of objects in the field, so that drawings may be made.

Velocity of Light in the two Media.—The velocity of light is greater in air than in water; and, in general, it is greater in the less refracting than in the more refracting medium.

The ratio of the two velocities is also found to be equal to the index of refraction, or

$$\frac{\sin i}{\sin r} = \frac{v}{v'} = \text{index of refraction.}$$

The angle i is in the same medium where the velocity is v.

Law of Least Time.—If a man were required to travel over uniform ground, from a point B to a point A (see Fig. 194), in the least possible time, his path should be a straight

line joining the two points. If, however, A is in a meadow, where he can run with a velocity of 8 miles an hour, while B is on plowed ground, where his speed can not exceed 6 miles, the boundary between the two surfaces being $h\ m'\ m\ h'$, then his path must be differently chosen.

By selecting some path A m B, the total distance traveled is greater than A m' B, but a larger fraction of it is over the smooth ground, where the velocity is greater. By choosing m to the right of m', an advantage in time is gained, notwithstanding the greater distance. But if m is chosen too far to the right, as at h', the increase in the total distance will more than compensate for the advantage of traveling the greater distance over good ground. The point m should be so chosen that the runner is refracted at the boundary, as light is refracted in passing from one medium to another.

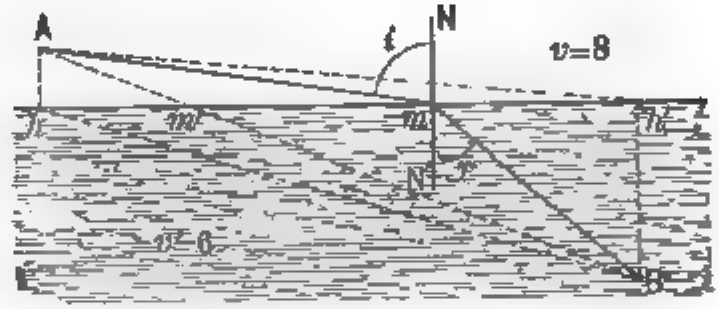

FIG. 194.—ILLUSTRATING THE DIFFERENCE OF VELOCITY IN DIFFERENT MEDIA, AND THE LAW OF LEAST TIME.

If we consider A m N and B m N' the angles of incidence and refraction, then

$$\frac{\sin i}{\sin r} = \frac{v}{v'} = \frac{8}{6} = \frac{4}{3}.$$

Mr. Haughton observed, on the beach near Swansea, some oyster-women who furnished an illustration of this law. In a course between points situated like A and B, the hard walking was a strip of rough, slippery shingle between the water and a smooth common. They were all refracted at the boundary-line, unconsciously choosing paths which reduced their labor to a minimum. The path is the same, whether the journey be from A to B or from B to A.

PROBLEM.—If A h = 2 miles, h' B = 6 miles, and h' h = 20 miles, find the distance h' m for minimum time. Find the times for the four paths A h B, A m' B, A m B, A h' B.

QUESTIONS.—When light strikes a transparent body, is it all reflected? Instance a familiar example which proves that rays are bent on passing from one medium to another. Explain what is meant by the index of refraction. State the index of refraction for air-water; for air-glass; for water-glass. Describe the appearance of a stick partly immersed in water. Show by diagram how points on the stick must appear to change their real positions. Why

do fish appear nearer the surface than they really are, and where must one aim in shooting at fish with a rifle-ball?

Describe the appearance of water to one looking outward from the shore. How much deeper is water immediately under a bather than it appears to be? *About one third.* Is it true that we see the sun before it actually rises? Why is this? Perhaps you can further explain why objects on either side of a hot stove-pipe seem to have a tremulous motion; why stars twinkle. What causes a diamond to sparkle? On what principle may imitation stones be detected?

Explain the phenomena of Total Reflection. Illustrate with a glass cube. What is the critical angle? Describe the appearances from a view-point beneath the water. Give an account of the shooting-fish. Is the velocity of light different in different media? State an interesting analogy between the refraction of light and the refraction of a runner in passing from smooth to rough ground.

PRISMS AND LENSES.

An Optical Prism is a refracting mass, bounded by planes inclined at any angle. Prisms have two effects upon light passing through them:

I. The light is refracted, or bent out of its course.

II. The light is dispersed into a spectrum of colors. This second effect will be discussed under the head of Color.

Let *a b c* be a section of a glass prism at right angles to the edges. A ray of light from *o*, entering the prism at *d*, is bent toward the normal. Passing on to *e*, it is bent away from the normal in again entering the air. Both of these effects deviate the ray in the same direction. The object *o* appears to be at *i*, in the line of direction which the ray has on reaching the eye. The original direction of the ray was *o h*, and the final direction is *i h*. The ray has therefore been deviated through an angle *o h i*, which is called the angle of deviation.

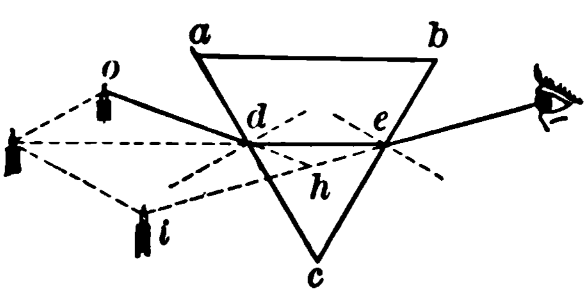

FIG. 195.—REFRACTION BY MEANS OF A PRISM.

A liquid or gas can, for the purpose of experiment, be confined in a hollow prism made of glass plates cemented to a triangular frame or box of metal or glass. Glass bottles of this form are in common use.

When the sides of a glass prism are parallel, it becomes a plate of glass. At the second face, the ray is restored to its original direction and proceeds in a parallel path.

Loss of Light by Multiple Reflection.—When a ray of light falls upon a plate of glass, part of the light is reflected, and part enters the glass and is incident upon the second face. At the second point of incidence, the light is again divided, part passing through the surface into the air, in a path parallel to the ray's original direction, the other part being internally reflected. This latter ray strikes the first face, where part passes out into the air, and another part is again internally reflected.

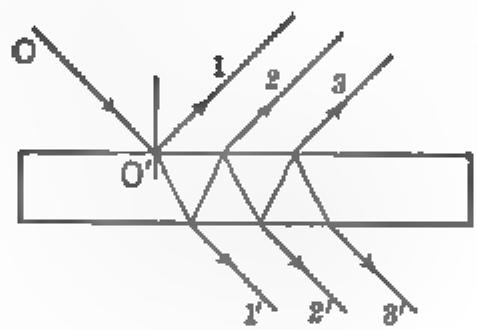

FIG. 196.—LOSS OF LIGHT BY REPEATED REFLECTION.

Fig. 196 shows the first reflected ray, two emergent rays from the first face, and three emergent rays, 1', 2', and 3', from the second face. The greater portion of the light is contained in the first transmitted ray.

Lenses are masses of glass, bounded usually by spherical surfaces (see illustration, page 293). Various forms of lenses in use are shown in Fig. 197. The shaded part of 1

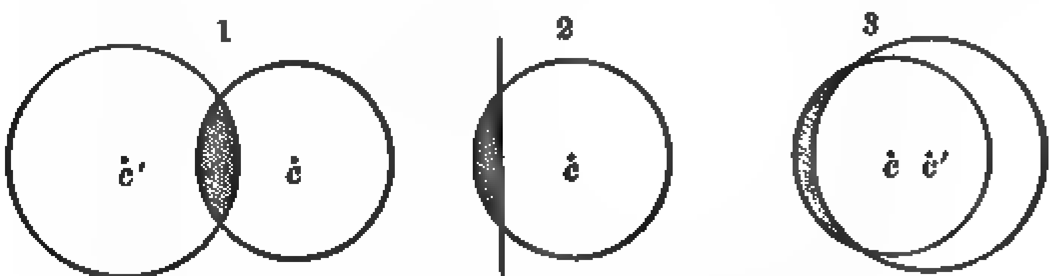

FIG. 197.—FORMS OF LENSES BY INTERSECTION OF SPHERES.

represents a *double convex lens*, which may be described as the space common to two intersecting spheres.

If the center c' of the left hand sphere be supposed to move to the left an infinite distance, the size of the sphere would be so increased that the part which intersects the second sphere would practically become a plane. A lens formed by such an intersection is a *plano-convex lens*, and is shown in 2.

If the center c' be moved to the right of c as in 3, the surfaces will bound a space concave on one side and convex on the other. A lens

thus made is called a *meniscus*. These three lenses are thicker at the middle than at the edges.

If the two spheres do not quite intersect, the space between their surfaces will have the form of a *double concave lens*. Such a lens would be bounded by the two spherical surfaces, and a cylinder, whose axis passes through the two centers, as is shown in 4.

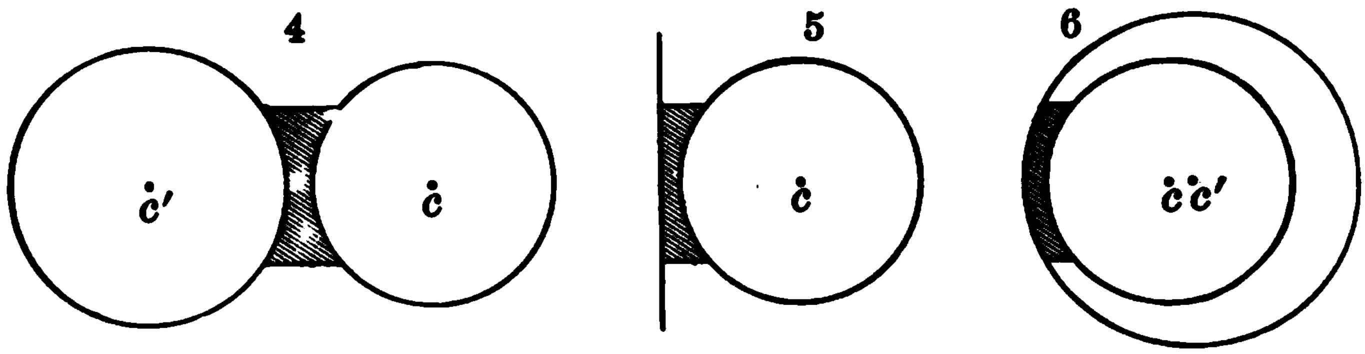

FIG. 193.—FORMS OF LENSES WITH CONCAVE SPHERICAL SURFACES.

Moving the center c' to an infinite distance to the left, we form the *plano-concave lens* shown in 5; and, finally, if the center c' is on the right of c, we have the *concavo-convex lens* shown in 6. The last three lenses are thinner at the center than at the edges.

Definitions regarding Lenses.—The center of curvature of any face of a lens is the center of the sphere of which it is a part.

A line drawn from the center of curvature of any face to any point of that face is called the normal at that point.

The principal axis of a lens is the line passing through the centers of its two bounding spheres. If the radii of the two spheres are equal, the point on the principal axis, midway between the two faces, is called the optical center.

Any straight line through the optical center is called a secondary axis.

Lenses 1, 2, and 3, of Fig. 197, have the same effect upon light as two prisms with their bases together. They cause parallel rays to converge toward the axis. They increase the convergence of converging rays, or diminish the divergence of diverging rays. Lenses 4, 5, and 6 will diverge rays from the axis.

Principal Focus of Converging Lenses.—The double convex lens will serve as a type of converging lenses. The principal focus is the point to which parallel rays are con-

verged, after passing through the lens. The principal focus of any lens can be determined by a mathematical calculation, when the radii of its bounding faces and the index of refraction are given.

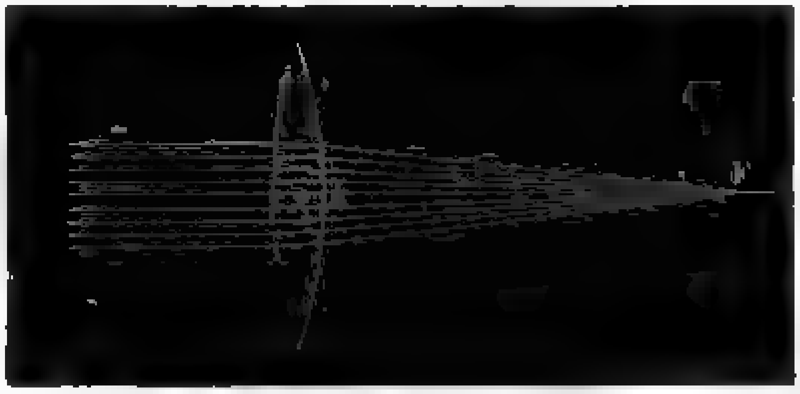

FIG. 199. PRINCIPAL FOCUS OF CONVEX LENS.

The distance, F A, from the principal focus to the lens is called the *focal length*. It shortens as the convexity of the lens, or the refracting power of the material of which the lens is made, is increased.

If a common glass lens be immersed in water, the principal focus will be about four times as far from the lens as it is in air.

Principal Focus of a Diverging Lens.—When rays parallel to the principal axis fall upon a double concave lens, they also undergo two refractions. But they issue from the lens in a divergent beam, which seems to have come from a point F. This point is the principal focus of the lens.

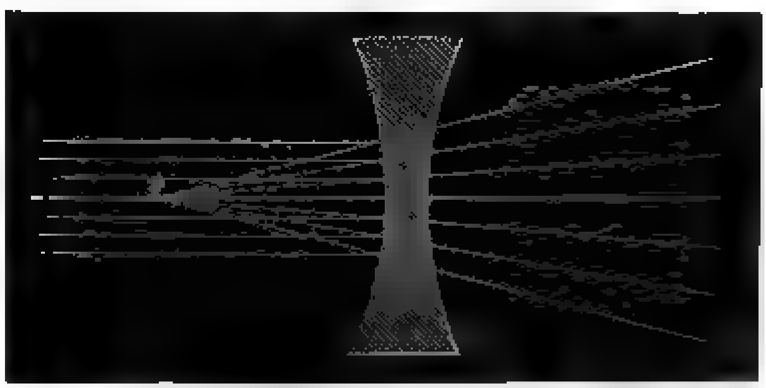

FIG. 200.—PRINCIPAL FOCUS OF CONCAVE LENS.

Real and Virtual Foci.—The principal focus of a double convex lens is a real focus. Parallel rays, after passing through the lens, are actually converged there. The principal focus of a double concave lens is a virtual focus. Parallel rays, after passing through the lens, seem to have diverged from that point.

If a double convex lens, as an ordinary pocket glass, be held in the sunlight, the image of the sun is formed in mid-air. It may be rendered visible by smoke or dust in the air, or it may be projected on paper. The virtual image of the sun formed by a double concave lens can not be projected on paper. It has no real existence; it is an optical illusion. It can be seen at F, if the eye is placed in the divergent beam.

Conjugate Foci.—If the rays passing through the double convex lens proceed from a point O, farther from the lens than the principal focus, the rays will converge to a point I, which is farther away from the lens than the principal focus. If O moves away from the lens to an infinite distance, I will move up to the principal focus F. If O moves up to the principal focus, I will move away to an infinite distance, and the rays will emerge in a parallel beam. For each position of O, there will be a definite position of its image I.

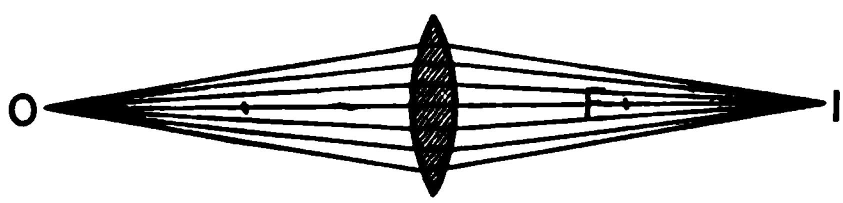

FIG. 201.—CONJUGATE FOCI.

In all these cases, if the radiant point O be placed at the position occupied by the image, the image will appear at the former position of the object. The object and image have changed places, and the light retraces its former path. Points thus related are said to be *conjugate foci.*

Foci of a Double Concave Lens.—If rays diverge from a point upon a double concave lens, they will, on leaving the lens, diverge more widely than if they had entered in a parallel beam. To an eye placed in the divergent beam, the light will seem to have come from a point I, which is nearer the lens than the principal focus.

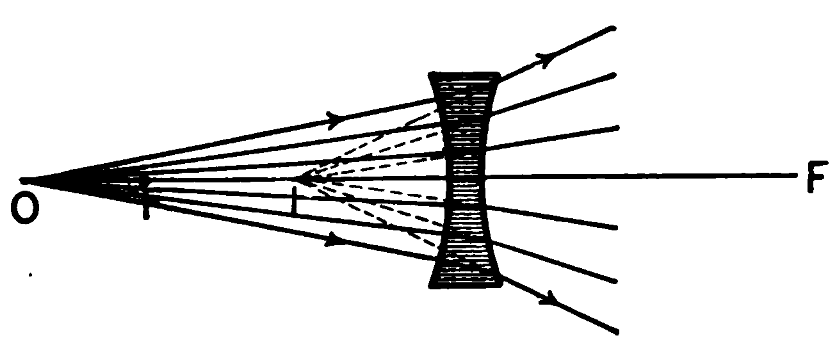

FIG. 202.—FOCI OF A DOUBLE CONCAVE LENS.

It will be observed that the two points occupied by the object and its image are not conjugate in this case.

Virtual Foci of a Double Convex Lens.—If the radiant point be placed nearer to the lens than the principal focus, the rays will diverge after passing through the lens. The point I, from which they seem to have diverged, will be a virtual focus. The nearer the radiant point O is to the principal focus, the farther I will be from the lens. The object and its image are not at conjugate points when the image is virtual.

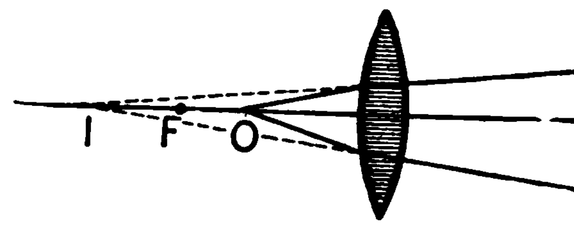

FIG. 203.—VIRTUAL FOCI OF A DOUBLE CONVEX LENS.

Formation of Images by Lenses.—Let A B represent any object. If rays proceed from the extremities A and B through the optical center, they pass on without refraction. Such rays follow the line of the secondary axis. The image of B will be somewhere on the secondary axis through B. Draw any other ray from B, and find where it intersects the secondary axis through B, after passing the lens. This intersection will locate the image of B, since all rays diverging from B and passing through the lens will converge to the same point. Such are the conditions under which an image will be formed, reproducing the object in shape and color.

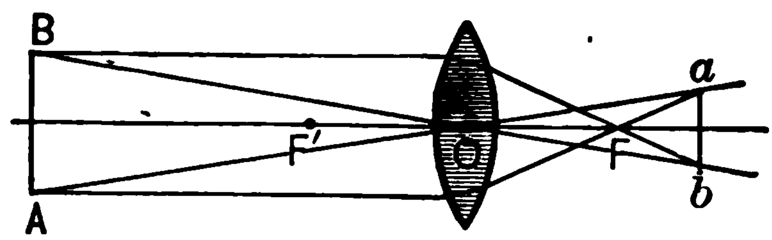

FIG. 204.—FORMATION OF IMAGE BY A LENS.

It is convenient to select, as the second ray radiating from B, that one which is parallel to the principal axis. This ray passes through the principal focus, F, and thence on until it intersects the secondary axis, in *b*. Similarly, rays from A, on passing through the lens, will converge upon the secondary axis through A at *a*. Thus the image will be inverted.

Evidently, if *a b* were the object, A B would be the image. The object and image may change places. Or, if A B were to move toward

the lens until its distance becomes equal to the present distance of the image, *a b* would recede until its distance equals the present distance of the object. The object and image occupy conjugate foci. The image is always real when the object is outside of the principal focus.

Virtual Image.—If the object is nearer the lens than the principal focus, the image will be virtual, magnified, and erect. (See Fig. 205.) The image of each point of the ob-

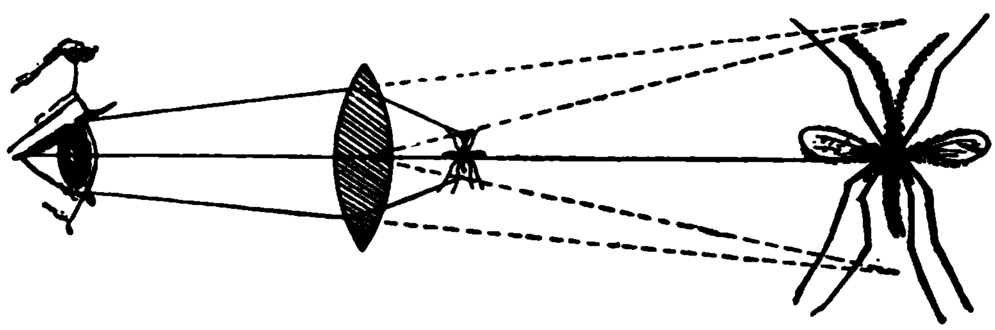

FIG. 205.—MAGNIFIED IMAGE OF HESSIAN FLY BY CONVEX LENS.

ject will be on a secondary axis through that point, in all cases, whether the image be real or virtual.

When the lens is used as in Fig. 205, it is called a simple microscope. Pocket-lenses and reading-glasses magnify on this principle.

Images by Concave Lenses.—Images formed by concave lenses are virtual, erect, and diminished. They can be seen through the lens, being on the same side of the lens as the object.

Can you draw a diagram illustrating the path of rays through a double concave lens, and showing why the image is reduced?

Spherical Aberration.—The rays which traverse a converging lens near the margin do not come to a focus at quite the same point as those which pass through the central portion. They are more refracted, and hence converge at a point F′, nearer the lens than the point F, at which the more central rays meet. This causes indistinctness in the resulting image. To render it sharp, the marginal rays may be

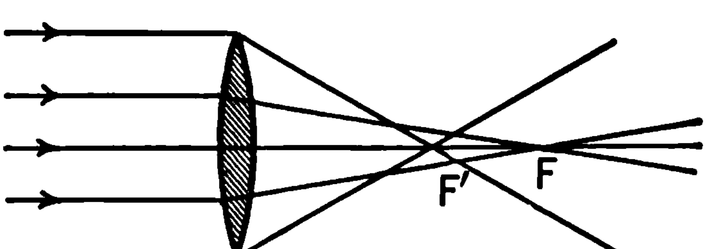

FIG. 206.—SPHERICAL ABERRATION EXPLAINED.

cut off by means of a plate with a circular opening, called a diaphragm (*di'a-fram*). The image formed by the central rays then becomes more distinct, but it is less bright. Spherical mirrors have the same defect.

Light a lamp, and with your reading-glass illustrate the principle explained above. A diaphragm may be made out of a piece of cardboard, and the central rays focused. If the central portion of the lens be covered with a circular piece of paper, the marginal rays may be focused. Measure the focal distance in each case, and compare the images with that formed by the entire lens.

Law of Intensity of Illumination.—The images from lenses are always formed in a fixed position when the position of the object with respect to the lens is once fixed. Moving the screen upon which the image is projected, will throw the image out of focus.

The images formed by a small opening (see Fig. 163) may be projected on a screen at any distance. Doubling the distance of the screen will double the linear dimensions of the image. The surface covered will, therefore, be four times as large, and since the amount of light streaming through the opening is the same in each case, the brightness of the image in the second position will be one fourth as great as in the first. The same principle applies to images formed by lenses; they vary in brightness inversely as the squares of the focal distances.

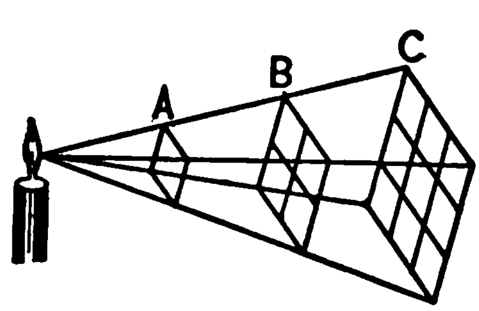

FIG. 207.—LAW OF INTENSITY EXPLAINED.

This law may be illustrated by placing a square card 1 foot from a candle, as in Fig. 207, at A. It receives from a given point in the flame a certain amount of light. The same light, if not intercepted at A, goes on to B at a distance of 2 feet. It there illuminates four squares of the same size as the card, and has, therefore, but one fourth of its former intensity. If allowed to proceed to C, 3 feet, it illuminates nine such squares and has but one ninth of its original intensity.

Thus the intensity of light diminishes according to the square of the distance from the source of illumination.

QUESTIONS.—Describe a Prism. Name the two effects of prisms on light. Explain the course of a ray of light through a prism. What can you say of the loss of light by repeated reflection? Define Lenses. Name and describe each kind of lens. What is the center of curvature of a lens? The normal? The principal axis? The secondary axis? The principal focus? Distinguish between real and virtual foci. What is the focal length, and by what is it determined? Explain conjugate foci.

How are images formed by lenses? When are they inverted? Suppose the object to be nearer a convex lens than the principal focus; describe the image formed. How can you verify this with your simple pocket microscope or reading-glass? Describe the image formed by concave lenses. What is Spherical Aberration and what does it cause? How can you illustrate it? Demonstrate the law of intensity of illumination.

COLOR.

Decomposition of Light by Prisms.—If a triangular prism be placed in the path of a slender beam of light (see Fig. 208), instead of a round, white image of the sun, we

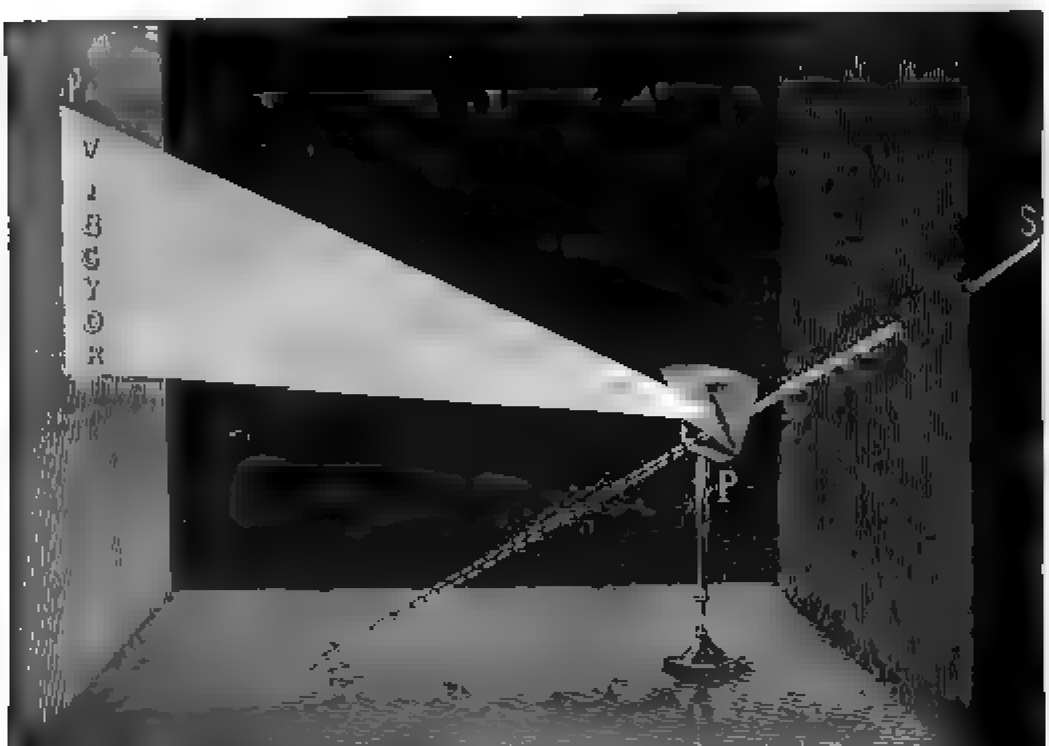

FIG. 208. DECOMPOSITION OF WHITE LIGHT BY TRIANGULAR PRISM.

observe a band of color. The light is refracted, as has been already explained, but it is not all equally refracted. At one extremity of the band, or *spectrum*, the light is violet;

indigo, blue, green, yellow, orange, and red succeed, each imperceptibly merging into that which follows.

The violet light is most refracted, being deflected through the angle V P E, while the red light is deflected through the angle R P E. This phenomenon is called dispersion.

The band of color is, in fact, a series of overlapping images of the sun (see page 297). These images can be again superposed by a second prism or by a convex lens, as in Fig. 209. The resulting image is white.

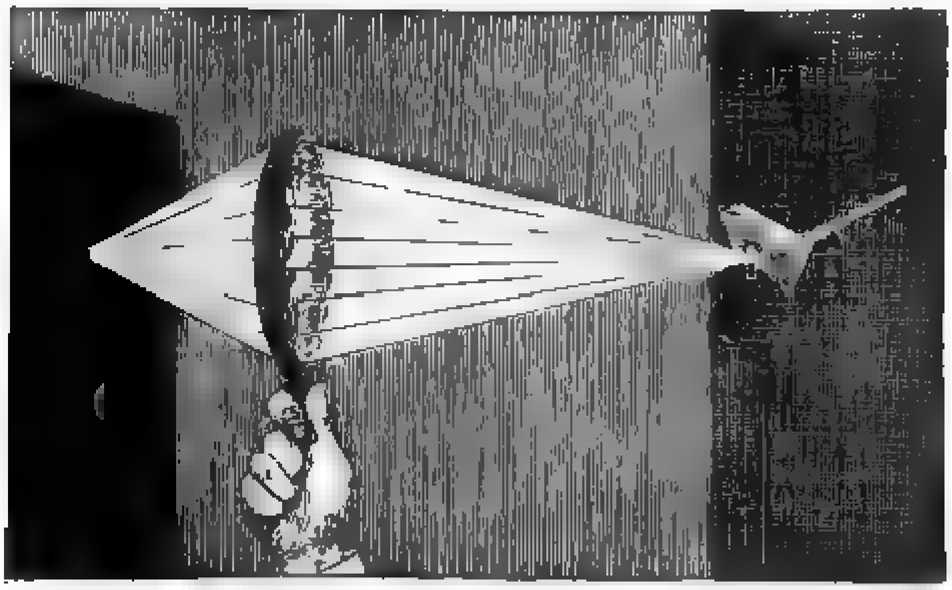

FIG. 209. -RECOMPOSITION OF WHITE LIGHT BY CONVEX LENS.

These two impressive experiments prove that the white light of the sun is composed of the colors seen in the spectrum.

Prisms of Different Material, as crown-glass, flint-glass, quartz, rock-salt, and water, having the same angle, will refract light unequally. If the angles of the prisms are adjusted so that they all deviate the red ray through equal angles, the violet rays will still be deviated through different angles. In other words, the spectra will have different lengths. Flint-glass gives, under these conditions, about twice as long a spectrum as crown-glass.

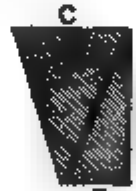

FIG. 210.

In Fig. 210, F represents a prism of flint-glass, and C one of common glass, whose angles are so adjusted that they give spectra of the same length. When placed as shown in the figure, one will therefore neutralize the dispersive effect of the other, and the emerging beam will be white light. It will, however, have been deviated toward the base of prism C.

Chromatic Aberration.—A combination of lenses or prisms in which dispersion into color is neutralized, is said to be *achromatic.* Objects seen through ordinary lenses are surrounded by a fringe of color, which, like spherical aberration, interferes with definition. This arises from the fact that rays of different colors are refracted to different foci, involving the formation of a number of images partly overlapping one another. The defect is known as *chromatic aberration*, and is corrected by combining a convex lens of crown-glass with a concave lens of flint-glass.

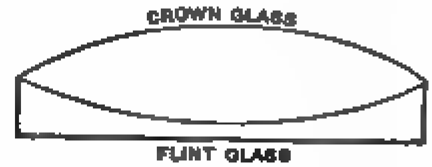

FIG. 211.—ACHROMATIC LENS.

Suppose the prisms just illustrated were of the same material, when would they become achromatic? Would there then be deviation of the ray?

Spectrum Colors otherwise combined.—The refracted light from a prism may be reflected to the wall of the room by means of a hand mirror. Give the mirror a rapid motion to and fro. Each color of the spectrum will be drawn out into a band, as in the case of a point of light on the end of a stick when whirled in a circle. If the mirror is so moved that these bands coincide, the resulting band will appear white in its central

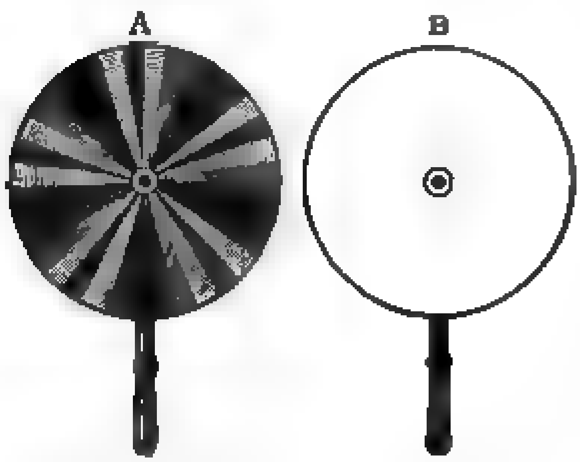

FIG. 212.—NEWTON'S DISK.
The card A bears the seven spectrum colors, repeated five times.

part, where all the colors overlap. Notice that the ends of the band are colored, and explain their appearance.

A Newton's Disk consists of a circular piece of cardboard, having colored sectors. The sectors may be of tinted paper, pasted on a card, as in A, Fig. 212. If the disk is spun rapidly round, the color impressions blend, and it appears of a grayish-white color, B. (See No. 2, introductory cut, page 293.)

The experiment may be successfully performed if the spectrum colors are represented on the disk but once, in proper proportion.

In the experiments just described, the colors are combined through persistence of vision. At any given instant, the image of each sector is formed at a certain point on the retina of the eye. As the sector revolves, its image moves round in a corresponding path upon the retina, returning quickly to its original position. During this rapid revolution, the sensation produced has not had time to die out, and the impression therefore appears continuous. The rapid recurrence of each colored image has the same effect as a simultaneous impression of all.

If a colored sector is put on a black disk and the disk revolved, the effect will be that of the color diluted with black, the precise appearance depending upon the relative amounts of colored and blackened surface. A white diluted with black will give gray, which is a dull white.

Mixing Colors by Reflection.—Place two rectangular pieces of paper, one yellow and the other blue, upon a black surface. Hold a strip of thin glass, G (see Fig. 213), so that the reflected image of the yellow paper seems to cover the piece of blue paper seen obliquely through the glass. The resulting color will be a mixture of the two tints.

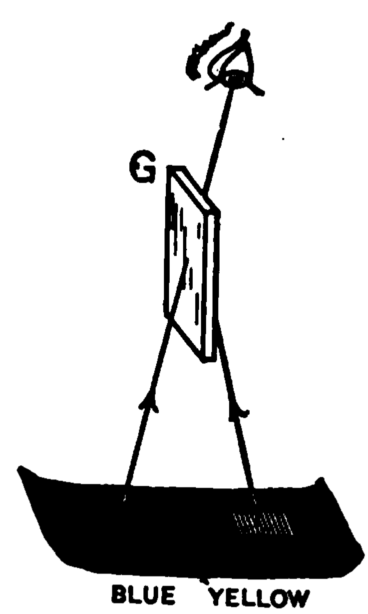

FIG. 213.—COLORS MIXED BY REFLECTION.

Vary the height of G above the papers. At a certain distance the mixture will appear a dull white. If the glass is raised the color will be yellowish, and if depressed it will be bluish. Why?

Complementary Colors.—All the colors of the spectrum, when mixed by a Newton disk, produce, as we have seen, a white. Remove red from the disk, and the remaining colors will, on rotation, give a bluish green. Match this color by a colored paper, and place it upon the disk with red. Rotate the disk, and the result will be white. In the same way, orange and cyanogen blue, purple and green, will yield a white. In Fig. 214, the colors which are shown opposite one another, when mixed by a disk, will give white. Such colors are called Complementary Colors.

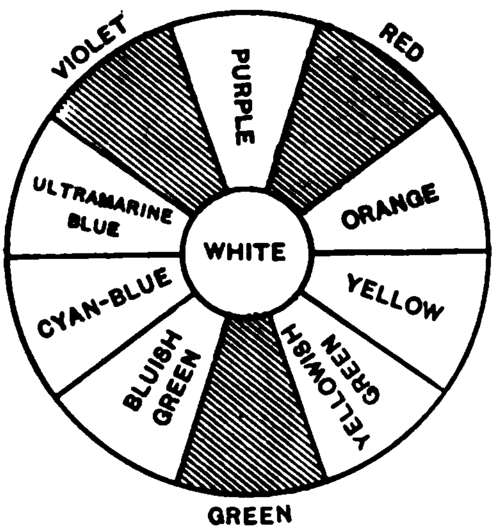

FIG. 214.—COMPLEMENTARY COLORS.

A combination of red and green in different proportions will produce the intermediate colors—orange, yellow, and yellowish green. From violet and green, the colors bluish green, cyanogen blue, and ultramarine blue can be obtained; while violet and red give purple. A mixture of no two colors will produce red, violet, or green. These are therefore called *primary colors*, while the others are called *secondary*, as they all can be obtained by mixing the primaries.

The eye is not able to distinguish between the white produced by mixing all the colors of the spectrum, and that formed from any two complementary colors, or from the three primary colors. In this regard, the eye has less power of analysis than the ear. When a harmony is rendered, the ear can detect each of the simultaneously sounded notes of every instrument, and the trained ear of one familiar with the music can single out any instrument in the orchestra, and detect an error in the playing.

Color of Mixed Pigments.—If the two pigments known as chrome-yellow and Prussian-blue be mixed, the result will be a green pigment; but the mixture of yellow and blue light will produce white light.

Blue and yellow light may be mixed on a screen by means of two magic lanterns, plates of colored glass being used as slides. The experiment is a very striking one, as shown in Fig. 215.

A similar experiment may be made with yellow and blue sheets of gelatine. Place the two sheets, Y and B, Fig 216, side by side, and

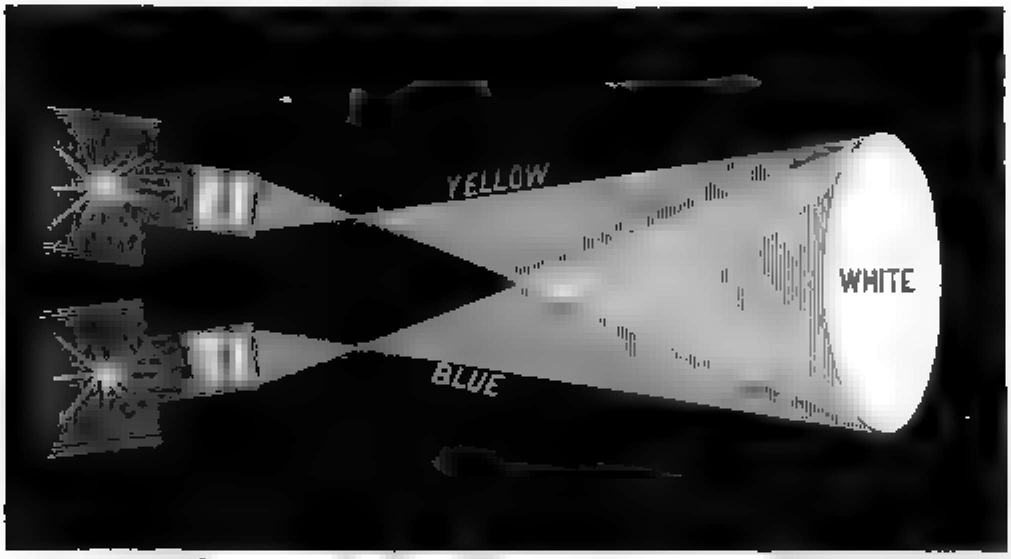

FIG. 215.—MIXTURE OF BLUE AND YELLOW LIGHT ON A SCREEN

send a beam of white light through each. Allow the two beams of light to fall upon a screen. One will appear yellow, and one blue. If the colored beams be passed through a prism, it will be found that the blue beam contains green, blue, and violet, with possibly a trace of red. Yellow, orange, and most of the red, have been quenched. The yellow beam has red, orange, yellow, and green; the blue and violet having been quenched.

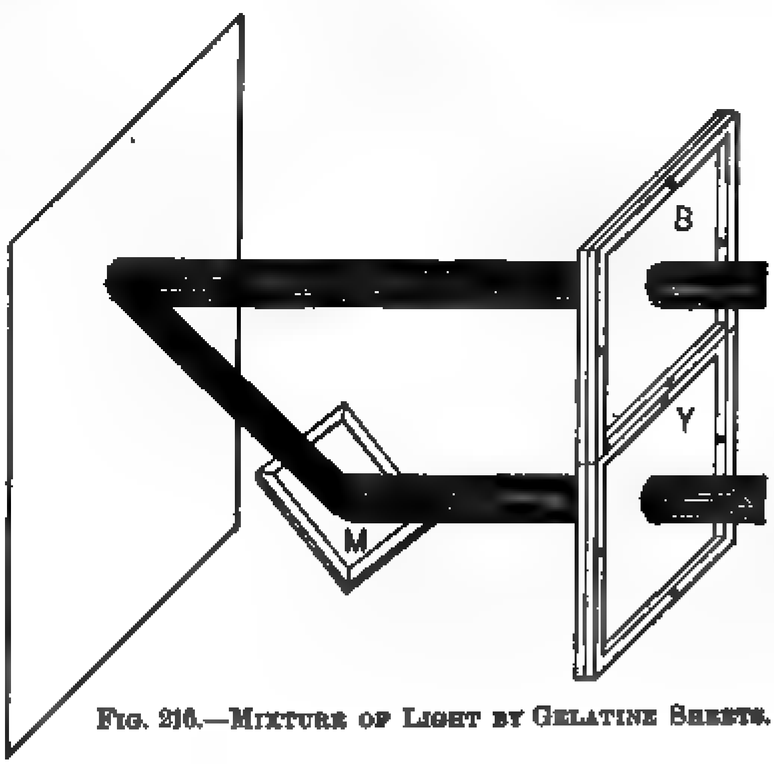

FIG. 216.—MIXTURE OF LIGHT BY GELATINE SHEETS.

If the yellow beam be reflected by a mirror, M, Fig. 216, so that the yellow and blue are combined on the screen, a white will be obtained. All the spectrum colors will be combined, and in approxi-

mately the same proportion as in sunlight. The action of the gelatines is represented by cancellation, as follows:

Blue gelatine, ~~R~~ ~~O~~ ~~Y~~ G B I V
Yellow gelatine, R O Y G ~~B~~ ~~I~~ ~~V~~

In Fig. 217, the light is passed successively through the two gelatines. The green, with perhaps a trace of red, is the only light which can pass through both, and this red with its equivalent green gives white. The result is to make a lighter green.

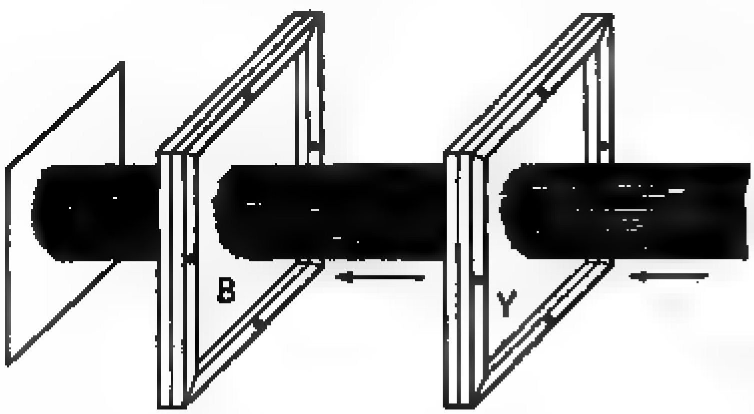

FIG. 217.—BEAM PASSING THROUGH GELATINE SHEETS AND FALLING ON SCREEN.

The blue gelatine may be replaced by a cell of copper-sulphate solution, and the yellow gelatine, by a potassium-bichromate solution.

If the gelatines gave pure yellow and blue lights, the result of their combination, as in Fig. 217, would be darkness, and not green. The yellow gelatine would transmit only yellow light. This would be quenched by the blue gelatine, which would transmit only blue.

Color of Bodies.—When white light falls upon a body, a portion of it is reflected from the outer surface. This light is white, as may be seen by reflecting sunlight from an unground colored glass (Fig. 218). Some rays are reflected from the first surface. These are not drawn in the figure. Part of the light enters the glass, and, being reflected from the lower surface, again emerges, and may fall upon the walls of the room.

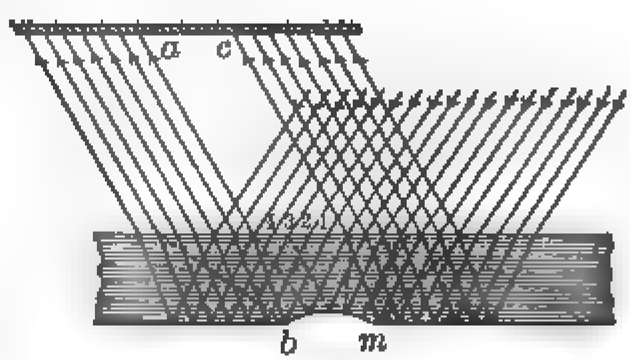

FIG. 218. REFLECTION OF LIGHT FROM GLASS.

An irregularity, like that shown greatly exaggerated at *b m*, would disperse the light, leaving a gap, as *a c*, in the reflection on the wall. Here the white light from the upper surface, from such rays as those marked 1, 2, 3, 4, will be observed.

So in all colored bodies, the colored light comes from the interior of the body, where it has been reflected from facets slightly below the surface. The color is due to light not quenched by the body.

When certain blue and yellow pigments are mixed, green is the only light which penetrates slightly below the surface, and is reflected out again, unquenched. If the pigments which artists use were all pure colors, a mixture of any two would give black, which would appear grayish on account of the white light reflected from the surface.

When light is quenched within a body, it is because the energy of vibration is used in setting the molecules of the body into motion. *The body is heated.*

The Color of Bodies thus depends upon their molecular structure. Different bodies quench different portions of the complex solar light. The unquenched light determines their color.

The color of bodies also depends on the light which falls upon them. If a loose bunch of candle-wick be moistened with strong brine and then with alcohol, it will, if ignited, give a pure yellow flame, called the sodium flame. It contains no red, green, or blue light. In a room illuminated only by this light, the red flowers and green leaves of a geranium or rose look exactly alike, being a dark gray. A stick of red sealing-wax appears dark brown or black. These bodies can not reflect yellow light. In a dark room, all things are black, or without color.

The clouds sometimes quench unusual portions of the sunlight, and all the hues of the landscape are changed. During storms, these changes often take place rapidly. The morning and evening sunlight contains less of the violet end of the spectrum than the noon sunlight, as the light travels a longer distance in air, in which the yellow and red rays are less affected than the others.

The Color-Sense and Color-Blindness.—Finally, the color of bodies depends upon the eyes of the observer. We can not describe our color sensations to one another. We are taught that the grass is green, the rose red; but it is probable that no two persons see colors alike, although they apply the same names to them. There are, in fact, many who can not distinguish a red or a scarlet from a drab or brown. To such persons, a pink rose has the same appearance as it does to the normal eye when seen by moonlight. They are said to be *color-blind* to red.

Color-blindness is the result of some disease or congenital defect in the nerves of the eye; it does not necessarily interfere with keenness of vision. Blindness for all colors is rare. A patient totally color-blind would be unable to distinguish between the red and white stripes in our flag, or the blue background and its white stars.

Color Fatigue.—We may readily convince ourselves that our own impressions of color are continually changing.

Cover the lower half of a sheet of white paper with a black, lusterless cloth. Let a strong light fall on the paper. Fix the eyes steadily upon some point in the boundary between the white and the black for about a minute. Then, without moving the eyes, withdraw the black cloth. The upper portion of the paper will appear a dull gray, in comparison with the section just uncovered, because that part of the retina upon which the brighter image was formed has become less sensitive. Ordinarily, we do not notice such changes, as they go on gradually, and we have no means of simultaneous comparison.

The white paper may be replaced by red. This will look dull after a minute of exposure to the eye, while the freshly uncovered red will appear strong, because its image falls upon an unfatigued part of the retina.

When the eye is fatigued for red, all other compound colors will, until the eye recovers, appear as if red had been stricken out of them. White will appear greenish, green will appear intensified.

Experiments.—Look at a strongly illuminated red on a black ground; then turn the eyes to a white wall. You will observe an after-image of the red spot, which will appear green. If the eyes be directed to a green paper, instead of the white wall, the after-image will appear a more intense green.

Look at a bright object, like a white cloud, through a green glass, with one eye, and through a red glass with the other. After a time, transfer both eyes to one glass, and open and close them alternately.

Look at objects through a red glass, with one eye, then through a green glass with the other; then look through both simultaneously. In which case do objects seem to have most nearly their natural colors?

When their eyes are fresh, artists are frequently dissatisfied with work done when their eyes were fatigued.

Mutual Effect of Colors.—Paste one circular piece of green paper on the center of a gray card-board, and another on the center of a red one. The green surrounded by red will seem much stronger. The red also appears stronger than it would if the green were absent.

Fix the eye upon the center of the green disk surrounded by red. At the same time, notice the colors at the boundary between the red and the green. Both colors seem stronger there than at some distance away. The fatiguing effect for red or green extends beyond the geometrical boundary of the images on the retina, and hence each color is intensified by the juxtaposition of the other.

Questions.—Explain the decomposition of white light by a prism. What kind of light is most refracted? Prove that white light is a mixture of all colors. Explain what is meant by chromatic aberration, and show how it is corrected. How may the spectrum colors be combined by a Newton's disk? Account for the persistence of vision in all such cases.

How may colors be mixed by reflection? By the use of two lanterns? By gelatine sheets? Why do we not obtain the same results by mixing colored lights as by mixing pigments? What are complementary colors?

On what does the color of bodies primarily depend? Follow the course of a ray of white light falling on a piece of colored glass. Why is the color of a body determined by light reflected from the interior? When light is quenched within a body, is heat generated? Why? How far is the color of bodies dependent upon the character of the light in which they are seen? Why is a violet blue? A calla-lily, white? Why are sunsets characterized by red and yellow tints? When is a substance black? What is white? What is black? Is either a color? Which reflects the most light? The most heat? Why are whites and straw-colors seasonable in summer? Dark-colored fabrics in winter?

How important a factor is the color-sense of the individual in the discrimination of colors? Describe color-blindness? What is color-fatigue?

THE SPECTROSCOPE AND SPECTRUM ANALYSIS.

The Spectroscope is an instrument used for the analysis of light. It consists of one or more prisms for the production of the spectrum, and a telescope for examining it.

The light is admitted to the prism through a narrow slit, S, in the end of the tube A (see Fig. 219), and then through a lens at the opposite end of this tube. The principal focus of the lens is at the slit. The light radiating from the slit upon the lens is rendered parallel, and passes through the prism to the telescope, B, which is first focused upon the slit. Instead of the sun as a radiant object, the illuminated slit is thus used.

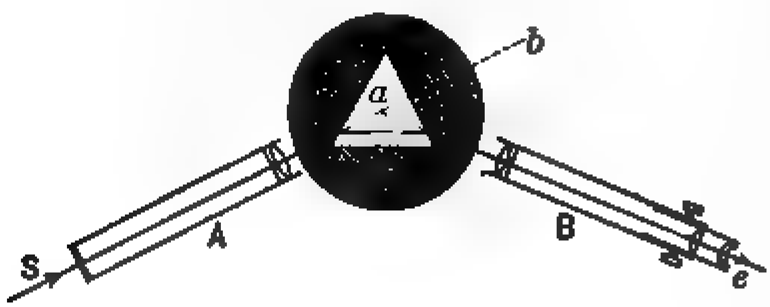

FIG. 219.—PRINCIPLE OF THE SPECTROSCOPE.

The light has been deviated through the angle *b a e*, which is measured by means of a divided circle on the bed-plate, B′. The telescope swings round the center *a*, and is first set in the line *a b*, being focused on the slit when the prism is removed. When the prism is returned to its place, the telescope must occupy the position shown at B in Fig. 219, in order that the observer may see the slit, which now appears widened out into a band of color,—the spectrum.

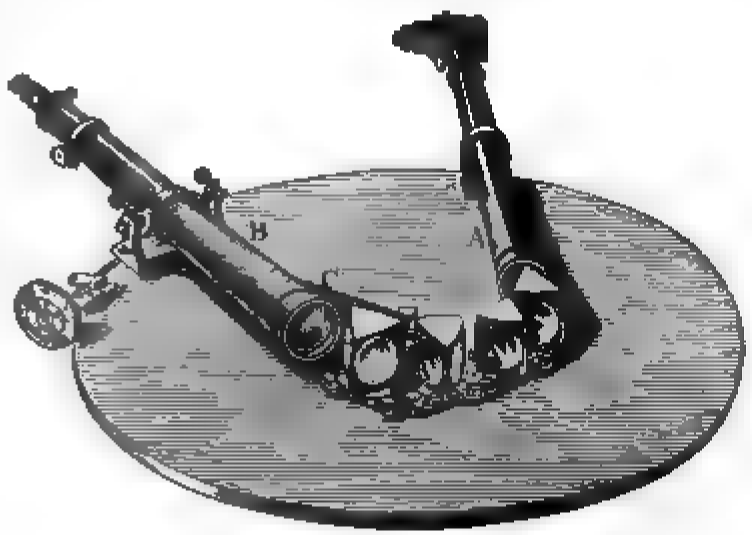

FIG. 220.—THE FOUR-PRISM SPECTROSCOPE.

Fig. 220 shows a form of spectroscope in which four prisms are used. Each prism increases the deviation and

dispersion of the light. Entering the slit in tube A, the width of which can be regulated by a screw, the light is bent round the train of prisms, and thrown back into the telescope B, being almost reversed in direction.

If the light from a white-hot solid or liquid body be examined with a spectroscope, a continuous band of all colors from red to violet is observed (as shown in Fig. 221).

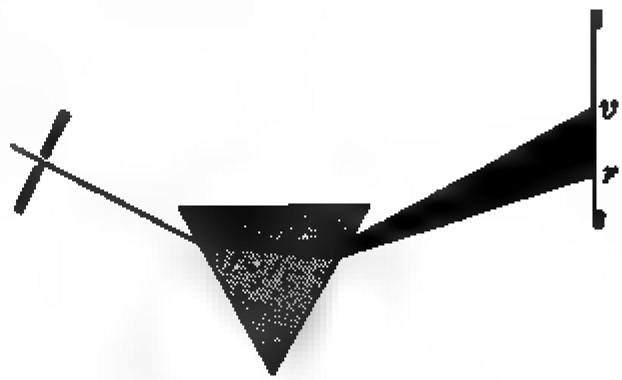

FIG. 221.—THE CONTINUOUS SPECTRUM.

When the glowing body is in the form of a gas or vapor, a different kind of spectrum is seen. For instance, if the yellow light of sodium vapor be observed, the spectrum consists only of a slender beam of yellow light. Not only is that part of the spectrum corresponding to red, orange, green, blue, and violet, wholly wanting, but the greater part of the yellow seen in a continuous spectrum of a white-hot solid is also blank. The yellow light of glowing sodium vapor is thus a very definite kind of yellow.

When the spectroscope is strong enough, it is distinctly shown that there are *two* slender beams of yellow light, very close together.

FIG. 222.—THE SPECTRUM OF SODIUM.

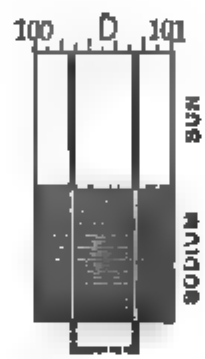

FIG. 223. SODIUM LINES.

By means of each of these beams, a sharp image of the slit is observed, the images being separated by a dark space. The lower part of Fig. 223 shows these two bright lines. They are also indicated at D, Fig. 224.

Other Bright-line Spectra.—Iron vaporizes when placed in the flame of an electric light. The light from

the glowing vapor, when passed through the slit of the spectroscope, shows a spectrum composed of hundreds of slender beams from red to violet, all separated by dark spaces. By means of each of these beams, a narrow image of the slit is seen, appearing as a bright line.

Every substance, when in a condition of glowing vapor, gives a bright-line spectrum on a dark background. As these spectra differ in the number and position of their lines, we are enabled to identify

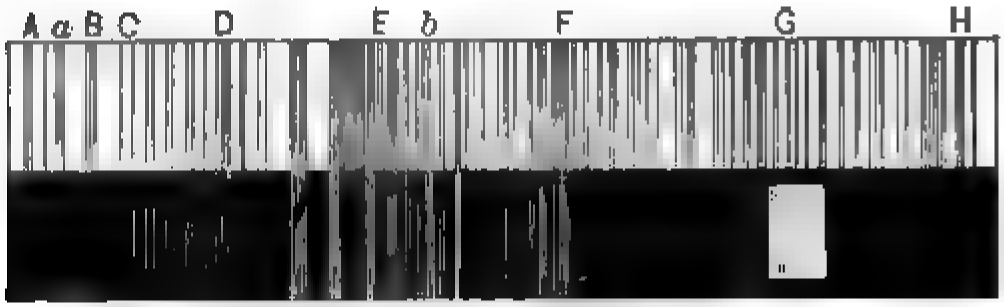

FIG. 224.—COINCIDENCE OF THE SPECTRUM OF IRON WITH 65 OF THE DARK LINES OF THE SOLAR SPECTRUM.

substances by means of the spectroscope. The appearance of the iron spectrum, as seen in an instrument of moderate power, is shown in the lower part of Fig. 224.

The continuous spectrum, as seen in the spectroscope, is simply a series of overlapping images of the slit.

The Solar Spectrum.—When sunlight is examined by a spectroscope, a band of color is seen; but when the telescope is focused on the slit, the spectrum appears crossed by hundreds of dark lines, as shown in the upper part of Fig. 224. Two of these dark lines are in the yellow, exactly where the two sodium lines occur. They are shown at D in Fig. 224, and in the upper part of Fig. 223. Thus our sunlight appears to be lacking in the kind of light which glowing sodium vapor emits.

So, also, the bright iron lines have each a representative line in the solar spectrum; but they are dark lines, suggesting that the light which glowing iron vapor emits is lacking in our sunlight. These two spectra can be produced at the same time. One shows a band of color with dark lines;

the other is a spectrum of bright lines, each of which is exactly opposite a dark line of the solar spectrum.

Fig. 224 shows some of the lines of iron, and their coincidence with dark lines in the sun's spectrum, the solar spectrum being above that of the iron spectrum.

The Dark Lines.—We might at first think that the apparent lack of sodium light in the sunlight shows the absence of sodium in the sun. This conclusion would be hasty and incorrect.

Focus the telescope on the solar spectrum when the sunlight is strong. Then place a Bunsen flame in front of the slit, and insert in the flame a piece of platinum sheet moistened with brine. The Bunsen flame may be replaced by a loose bunch of candle-wick, or old muslin torn into strips, moistened first with brine, then with alcohol, and ignited. If the sunlight be cut off, the bright line of sodium will be observed; if the sunlight be admitted, this line will become dark.

Now, if the sodium flame be alternately placed before the slit and removed, it will be found that the dark line is made darker by interposing the yellow sodium flame. A cloud passing over the sun may dim the brightness of the solar spectrum. The dark sodium line may then become bright, if the sodium flame be kept before the slit.

It is thus proved that the dark lines of the solar spectrum are really bright. They appear dark by contrast with the brighter adjacent portions of the spectrum.

If the sun were an intensely glowing solid or liquid mass, it would give a continuous spectrum, without either bright or dark lines.

But suppose this glowing mass to be surrounded by an atmosphere containing cooler (although brilliant) sodium vapor. This vapor would absorb light of the same kind as it emits, and hence a dark line would be left in the spectrum. As the previous experiment shows, we can even increase this absorption, by causing the sun's light to pass through more sodium vapor placed in front of the spectroscope slit.

Such considerations show that sodium, iron, and many other substances which we have on the earth, are present as vapor in the atmosphere of the sun and stars.

A Similar Case of Absorption.—Sweep a violin string with a bow, and at the same time slide the finger along the string, changing the note from the fundamental to the

highest note of which the string is capable. An infinite number of notes will have been successively produced. If all these notes were simultaneously produced, we should have a complex sound similar to the complex light of a white-hot body, having color ranging from red to violet.

Imagine this complex sound to proceed along a hall-way across which are stretched a multitude of wires, all attuned in unison to some definite pitch. The sound-waves in unison with these wires would largely exhaust themselves in setting the wires in motion, while the waves not in unison would pass through unchecked. The complex sound after passing through the wires would be lacking in precisely the sound which the wires produce if they are set in motion. If an adjustable resonator were used to analyze this complex sound (see page 404), it would be silent when adjusted to the pitch of the absorbing wires, and would give a loud response if its length were made greater or less.

It is thus that the molecules of sodium vapor in the solar atmosphere quench the same kind of light which they would give off if more strongly heated.

QUESTIONS.—Explain the principle of the spectroscope. Describe the four-prism spectroscope. Can artificial light be diffused by a prism? Is the spectrum formed always the same as that of the sun? Illustrate in the case of sodium vapor; in the case of the glowing vapor of iron. How may substances be identified by means of the spectroscope?

Describe the Solar Spectrum. Account for the dark lines. Why would it be incorrect to argue that the apparent absence of the characteristic light of any element in the sunlight proves the absence of that element in the sun? Cite an experiment in point. Are the dark lines really dark? How may they be the result of absorption of light? State a similar case of absorption of sound. Of what does the spectroscope show the heavenly bodies to be composed?

EFFECTS OF THE SOLAR RAY.

The Solar Ray exerts different effects upon different organs. Falling upon the retina of the eye, it produces the sensation of light, and different parts of the solar spectrum excite sensations of different colors. Its effect upon the sensory nerves of the body is to cause the sensation of heat. These nerves, however, can not distinguish between red

rays and violet rays, but only very crudely between rays of greater or less energy.

Invisible Solar Rays.—In like manner, by far the greater part of the solar spectrum is imperceptible to the eye. The spectrum extends somewhat beyond the violet and very far beyond the red. The existence of the invisible parts of the spectrum—the *ultra*-violet and *infra*-red—is proved by other means than the effect upon the eye. For example, the salts of silver will blacken in the dark rays beyond the violet, and delicate instruments for indicating heat show marked heat effects for several spectrum lengths below the red.

The instrument best adapted for these heat measurements is a slender strip of platinum, which is placed transversely across the spectrum and can be moved from one end to the other. By means of proper instruments, the electrical resistance of this platinum strip is measured. This resistance increases as the strip is warmed, and diminishes as it is cooled. Every dark line in the visible spectrum is found to be a cold line. When the instrument is moved far out into the ultra-red, the temperature falls as it passes through cold lines and bands, and rises when it encounters the warmer radiations that bound these on either side, all being wholly invisible.

Solar Light is essential to Vegetable Life; plants deprived of it wither and die. It is believed that the energy exhibited in the growth of plants is directly traceable to the green coloring-matter which occurs as grains in their cells, and which by absorbing rays of light transforms the energy residing in the molecules. The infra-red or heat rays are also an important factor in this process; but germination is furthered principally by the ultra-violet rays, which, by a provision of Nature, are in excess in the spring.

Chemical Effect of Sunlight.—If the dampers of a piano are raised and a given note sung, the string in unison will respond. No other string will do so. Persons with powerful voices have been known to shatter a glass vessel by singing into it the note which it would yield if

struck. Similarly, light-waves, beating upon certain substances, throw the molecules into a vibration sufficiently violent to shake them asunder. This is called a *chemical* change, and explains the fading of colors in sunlight. Silver compounds are particularly sensitive to decomposition by the blue and violet rays.

Photography depends upon this chemical action of light, an image formed by lenses being received on a sensitive film of iodide and bromide of silver exposed in a camera obscura (*dark chamber*). The silver salts are differently affected by the strong lights and shadows of the picture, so that the picture may be developed by a second operation.

The Photographer's Camera consists of an achromatic lens mounted in a wooden box, at the back of which is a ground-glass plate for the reception of the image projected by the lens (see Fig. 225). This image is real, inverted, and usually smaller than the object, and is visible on the ground glass to the operator. In order to facilitate focusing, the lens is usually movable in a brass tube, and the camera is provided with a rubber or cloth bellows by means of which the ground-glass plate may be pushed backward and forward. When a focus is obtained, the ground-glass

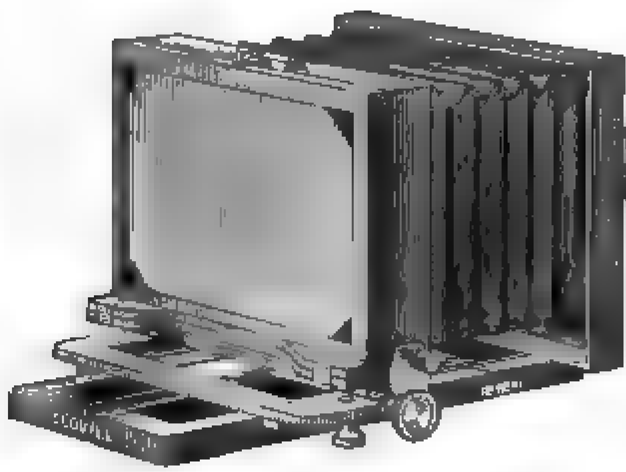

FIG. 225.—CAMERA BOX AND TUBE.

NOTE. The chemistry of photography is fully explained in the manuals of instruction issued by all reputable dealers in photographic materials. It is no longer difficult to become an expert photographer The Scovill & Adams Company, of New York, furnishes outfits at prices within the reach of all; and the young pupil, equipped with a camera and dry plates, can intelligently investigate both interesting phenomena of light and the chemical processes associated with one of the most fascinating of arts.

screen is removed, and a plate-holder containing a sensitized glass plate is slipped into its place.

When object and image are equally distant from the lens, they are of the same size. If the object is brought nearer, the image is enlarged, and in photographing from the microscopic field it is greatly exaggerated. Features invisible to the naked eye are thus magnified and photographed in the Photo-Micrographic Camera.

Microscopic photographs, or representations of large objects greatly reduced, are also made on glass of a size so small as to be visible only through a powerful magnifier. Small lenses of short focal length are employed to form images of microscopic minuteness. The contents of 10,000 volumes might in this way be so materially reduced as to be contained in a single drawer, but the photographs would have to be read through a microscope. Pages have been concentrated on a surface one inch square, and during the last siege of Paris trained pigeons carried to and from the city long dispatches thus reduced.

In good cameras, spherical and chromatic aberration are corrected by combining crown and flint glass in the lenses, and by the use of diaphragms.

The principle of the camera obscura is utilized by the draughtsman. A mirror is employed to reflect the landscape to a lens mounted in the top of a vertical camera; the rays are thus brought to a focus on a sheet of paper, forming a distinct image which can be readily traced with a pencil. The camera is large enough to admit the upper part of the draughtsman's person, a dark curtain excluding all light except what enters from above. A small tent supported by a tripod is sometimes used, enabling the artist to sit at a table within.

Questions.—Illustrate the different effects of the solar ray on the retina; on the nerves of the body; on germination and the growth of plants. Can the sensory nerves distinguish between red heat rays and violet heat rays? What parts of the spectrum are invisible to the eye? Describe an instrument adapted to measuring heat in the spectrum. How can you prove the existence of the invisible solar rays?

How may a glass vessel be shattered by sound vibrations? Similarly, describe the principle of chemical change by light; the fading of colors. What is the action of light on silver salts? Describe minutely the photographer's Camera, and the process of Photographing. When are object and image of the same size here? Explain the purpose of the Photo-micrographic Camera; the uses of microscopic photography. Describe the draughtsman's camera.

THE EYE.—MECHANISM OF VISION.

The Human Eye is a camera. Its outer envelope is quite fibrous and rigid, serving as a protection for the refracting structures within. It is called the white of the eye, or the sclerotic coat (see Fig. 226), gives attachment to the muscles that move the ball, and is connected with the dark-colored choroid coat which makes the chamber of the eye a camera obscura. In front, we have the transparent cornea, the colorless and transparent aqueous humor of the anterior chamber, and the elastic crystalline lens suspended in its capsule by the suspensory ligament. The glassy, jelly-like vitreous humor fills the posterior cavity. These structures serve to form a real and inverted image of external objects on a delicate nervous membrane called the retina, which lines the choroid coat at the back of the eye. The nerve-fibers of the retina gather into the optic nerve, the medium of communication with the brain.

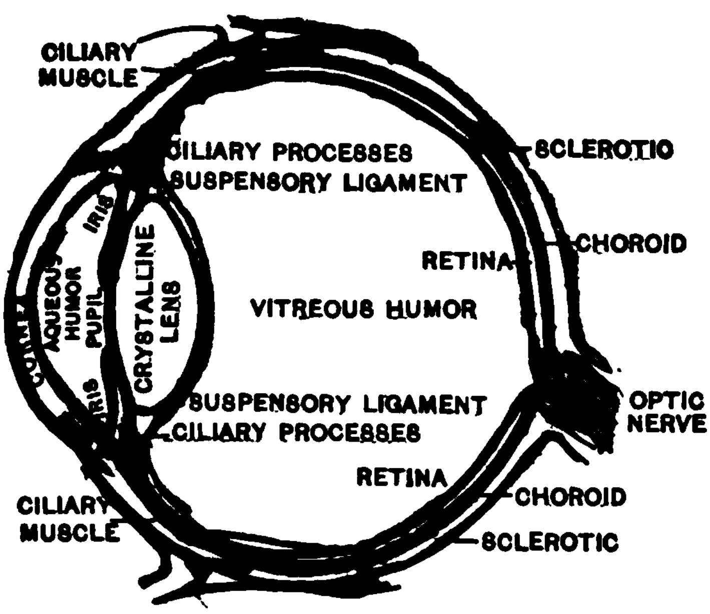

FIG. 226.—SECTION OF THE HUMAN EYE.

Spherical aberration is in part avoided in the eye by the curvature of the retina, and through the cutting off of marginal rays by a movable diaphram called the iris. It is the color of this diaphram which determines the color of the eye. The aperture in the center is called the pupil. The iris automatically regulates the size of the pupil, and hence the amount of light admitted to the eye-ball.

The Eyes Move through a considerable angle in their sockets in order that they may be directed upon any object. Accurate seeing is done only by a minute spot on the retina, called the *yellow spot*.

Fix the eye upon the middle of a line of this page and you will find yourself unable to read the whole line without moving the eyes. You have the power to direct the eye from the bottom to the top of a letter, the object of the act being merely to bring the image of the point to be observed upon the sensitive spot.

When the sky is clear, the planet Venus is usually visible at midday. It is, however, very difficult to find the planet, although it is distinctly seen when found. This shows that the sensitive spot is extremely small.

Accommodation.—The eye, like the camera, requires to be focused for objects of varying distance. This is accomplished mainly by a change in the curvature of the front of the lens, accompanied with a corresponding increase, for a near object, of the existing refraction of the eye (see Fig. 227). The eye is represented in a state of rest in the right half of the diagram, and in strong accommodation for near vision on the left. It is through this power of accommodation that we are enabled to see distinctly both near and distant objects.

FIG. 227.—CONDITION OF EYE AT REST AND IN STRONG ACCOMMODATION

Looking at a near object requires a fatiguing effort of the ciliary muscles (see Fig. 226), which relax the suspensory ligament, allowing the elastic lens to become more convex. The eye is rested by fixing it on a distant object.

Single Vision with Two Eyes.—The axis of the eye is a line passing through the center of the pupil and the sensitive spot. When we look at anything, the axes of the two eyes converge upon it and it is seen as a single object. Two images are formed, but they impress corresponding points of the two retinæ, and hence the notion of a single object is conveyed.

Fix the eyes on a door-knob, or any small object, and gently push one eyeball aside with the finger. The images are thus made to fall on non-corresponding points of the retinæ, and the object is seen double.

The Visual Angle, bounded by two lines drawn from the eye to the extremities of any object, measures the apparent size of that object. Thus, the apparent sizes of the sun and moon are about the same, although the radius of the sun is nearly twice the distance from the center of the earth to the moon. In Fig. 228, the visual angle of the arrow B A is *b* E *a*, and that of the arrow C D is *c* E *d*.

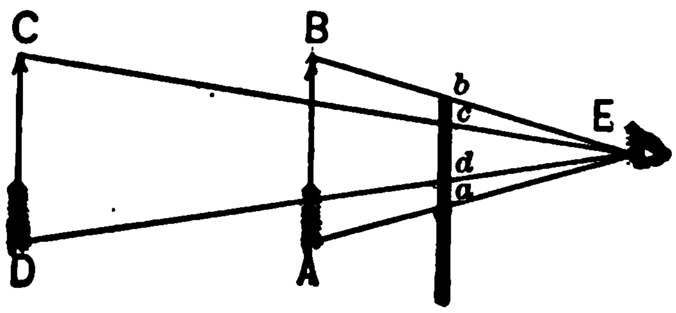

FIG. 228.—THE VISUAL ANGLE.

A given object looks large or small according to the visual angle under which it is seen. If we measure the apparent lengths of the equal arrows by an interposed rod, the nearer one will measure *a b*, and the farther one about half as much, *c d*.

The visual angle of the sun is nearly the same as that of a nickel five-cent piece held about seven feet away.

When the visual angle is less than two minutes, the details are invisible. The object, if bright, is seen as a point.

Estimation of the Real Magnitude and Distance of Bodies.—A person born blind and obtaining his sight after having been educated as a blind man, can not recognize bodies by the newly acquired sense, but continues to do so by touch. He handles objects again and again, and memorizes their names in connection with their colors and forms, knowledge of colors being all that the eye primarily gives. Everything appears to him as if painted on a screen, so that notions of distance and magnitude have to be acquired by slow experience, as in the case of every child.

When strange objects confront us, they are generally near familiar things and on familiar ground, and we at once estimate their size by

comparison; but when we are placed amid unfamiliar surroundings, we make ludicrous mistakes. In a wild, mountainous country, we are likely to mistake a mountain covered with enormous trees, twenty miles away, for a hill grown with bushes within two miles. In such a landscape, the presence of a man or a house at once enables us to form more correct estimates.

We can judge of the distance of a familiar object by its apparent size, and we can estimate the size of an unfamiliar object on familiar ground; but where real magnitudes and distances are unknown, the apparent size affords no information regarding either. Hence, on the top of Mount Washington, or in the parks of Colorado, a visitor from the seaboard is often deceived by the apparent nearness of distant objects in the clear and rarefied air.

Why we see Objects Erect.—The image on the retina is inverted, and yet we see and localize objects as they are. The reason of this is that we do not see the retinal image in the same sense that we see external things. In fact, the mere image on the retina affords no information to one who has not been trained to interpret its meaning by touch.

Engineers who use a telescope in which everything is seen inverted, soon learn to look through the telescope at the rodman and direct his movements without noticing that they see him inverted, and that they direct him to move in an opposite direction from that which is apparently right. When thus trained, an engineer, using a telescope in which everything is seen erect in its real position, would continually make mistakes. While using such instruments alternately, an observer is frequently compelled to make a deliberate examination to determine whether the image in the field is erect or inverted.

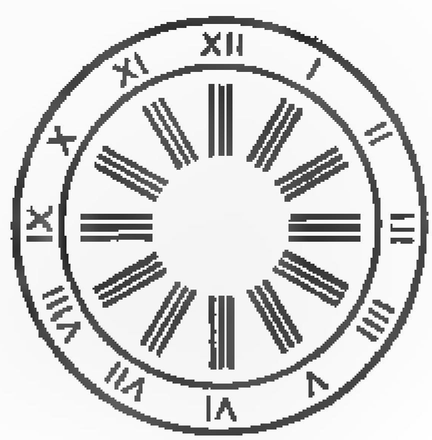

FIG. 229. -TO ILLUSTRATE ASTIGMATISM.

Optical Imperfections of the Eye.—Astigmatism.—The eye has many defects common to other optical instruments. The horizontal and the vertical curvature of the ball are different, so that when vertical lines are in focus, horizontal lines are out of focus.

Fig. 229 is a diagram used for proving this error. When held at a distance, the vertical sectors are often sharply defined, while the horizontal ones are blurred and indistinct. This fault exists to some extent in all eyes. When very marked, it is called *Astigmatism* (implying that the rays do *not* converge to *a point*). Astigmatism is corrected by means of spectacles of cylindrical curvature, either convex or concave.

Irradiation.—A luminous body looks larger than a dark one of the same size and shape. A red-hot wire and the hot carbon filament of an incandescent lamp appear very much larger than when cold, although the real change in dimensions by expansion is wholly inappreciable.

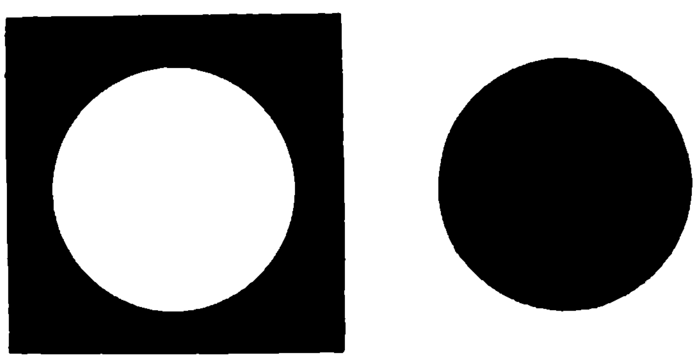

Fig. 230.—Illustrating Irradiation.

Look at a clean copper wire and then at a dull one of the same caliber. Hold a black wire against the sky, and then against a piece of white paper. What do you notice in each case? Glance at Fig. 230. The white circle surrounded by black looks larger than the black circle surrounded by white, although both are exactly the same size.

These experiments show that, in bright images, the retinal effects extend beyond the geometrical boundaries of the images. The same results are noticeable in photography, and the effect of complementary colors upon each other is similar. It is in accordance with this principle of *irradiation*, or apparent enlargement of brilliant objects, that persons of taste adapt the color of their clothing to their size and figure.

The effect of contrast is always to exaggerate. Small persons seem diminished in size when in the company of those who are taller, and *vice versa*.

Long and Short Sight.—Some eyes are elongated along the axis, so that the image is formed in front of the retina unless the object is held very near. Such eyes are said to be *near-sighted*. They are corrected by using diverging glasses.

Other eyes form the image back of the retina unless the object is held off at an inconvenient distance, in which case it often becomes indistinct. The correction is here made by convex glasses, as in persons of advanced years, who usually become *far-sighted.*

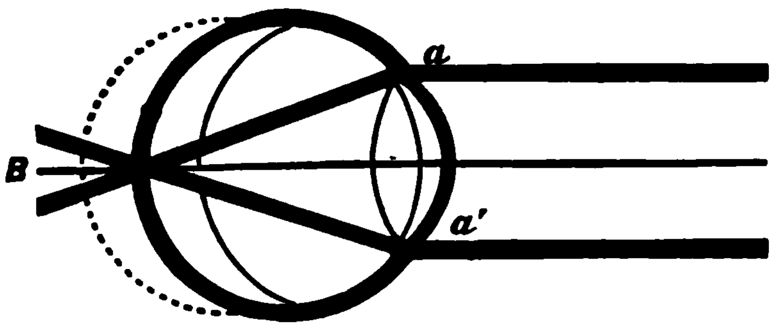

FIG. 231.—NORMAL, SHORT-SIGHTED, AND LONG-SIGHTED EYE.

In Fig. 231, the normal eye, and the rays *a* and *a'* coming to a focus on the retina, are represented by heavy lines. In the short-sighted eye, where the axis is too long, a dotted line marks the contour; an indistinct image is formed at B, beyond the focus. The far-sighted eye, with too short an axis, is indicated in the diagram by the hair line.

Other defects in the eye are noticed only by those who engage in unusual work. In many optical researches, where divergent light enters the eye, the field is seen full of fugitive shadows cast by particles floating in the liquids of the eye. They can usually be seen to a limited extent when one lies upon the back and looks at the sky, for when the body is erect they rise to the upper part of the ball, out of the line of vision.

Chromatic Aberration is another fault which the eye has in common with all lenses. Since violet light is more refracted than red light, the principal focus for violet rays will be nearer the lens than that for red rays. The foci for all other colors will lie between.

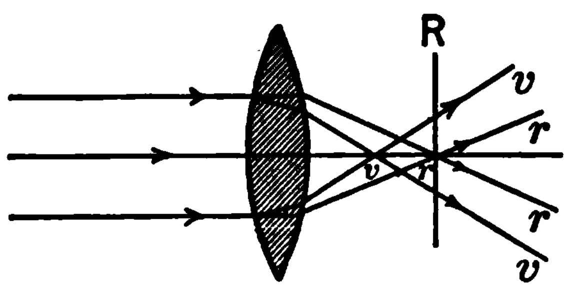

FIG. 232.—CHROMATIC ABERRATION.

The average eye when looking at a distant object is focused for yellow rays. The retina is at R. Violet will be focused in front of the retina, and will diverge into a circle upon it. Look at a distant gas-jet through a piece of blue glass. The glass will cut off yellow and green light, admitting blue and some red. You will see the flame red, surrounded by a blue halo. If you now use concave spectacles of proper curvature, you will throw the blue focus back upon the retina; the red focus will then be behind the retina, and you will see a blue flame surrounded by a red halo.

The Blind Spot.—The spot where the optic nerve enters the eye, is blind. To prove this, close the right eye, and, holding the book about six inches from the face, look with the left at the dot below. If properly adjusted, the

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cross will be invisible. Move the book nearer to, or farther from, the eye, and it will reappear. A large dot and cross may be placed on the blackboard, the size being greater in proportion to the distance. When the cross disappears, on approaching or receding, its image falls on the blind spot. If the left eye is closed, the right must be directed to the cross.

The image of a lamp-globe or the full moon may be shut out in this manner. The blind spot is large enough to cause the disappearance of seven full moons placed side by side.

The experiments described above prove that the optic nerve is blind, and that the true function of the retina is the mysterious conversion of vibrations of ether into the proper excitants of this nerve, whose fibers communicate to the brain sensations of light and color.

Care of the Eye.—The eye is admirably adapted to the wants of a pastoral or savage people, not even failing them in old age; but the increasing demands of a civilized life bring it into use under conditions which it is not so completely designed to satisfy. Injury to the eye may be prevented and its usefulness prolonged by observing the following precautions:—

Do not use the Eyes—1. In insufficient light, as in deepening twilight, or when the sun is obscured by a rain-cloud. 2. In excessive light, as the glare of the sun or of an electric arc. 3. In unsteady light, as that of a flickering gas-jet—the effect of persistent reading in a moving carriage or railway-train is in the end equally pernicious. 4. In hot light, as that of powerful kerosene burners, which over-congests the retina. 5. Do not sleep with a light in the room, as the eyelids are semi-transparent, and both retina and brain, which should have rest, are continuously irritated. 6. Avoid sudden and intense changes of light, as the pupil responds slowly. 7. Avoid light that enters the eye directly. While working, use an opaque

lamp-shade. The artificial light that most nearly fulfills the conditions of a perfect illuminator is the German student's lamp.

QUESTIONS.—Prove that the human eye is practically a camera. Describe minutely its anatomy; its several coats, its lens, its humors, the office of the iris. How can you prove there is a spot of distinct vision? How is the eye accommodated to objects of varying distance? Explain the principle of single vision with two eyes; of the determination of size and distance. On what does apparent magnitude depend? Why do the sun and the moon appear larger when near the horizon? How long is a child in acquiring an approximately correct appreciation of distance and magnitude? *About three years.* Why do we see objects erect?

What is astigmatism? Illustrate irradiation. Explain long and short sight. When an image is formed in the vitreous humor instead of on the retina, what kind of glasses are required? Why do old persons hold objects at a distance in order to see them distinctly? What kind of eyes require double convex spectacles? Can you give a reason for not forming the habit of reading while lying on the back? Explain chromatic aberration in the eye.

What is the blind spot? Describe experiments that prove its existence. State precisely the office of the optic nerve and of the retina. What precautions should be observed by persons desirous of preserving their eye-sight? Why does a sudden entrance into bright light give pain to the eye for a time? Why is it injurious to the eye to sleep with a lighted lamp in the room? Is it true that cats and owls can see in the entire absence of light? Will a diamond glisten or a cat's eyes shine in the dark? Why is the pupil of every eye black?

OPTICAL INSTRUMENTS THAT AID VISION.

The Stereopticon, the converse of the camera, is used for throwing magnified images on a screen in a darkened room. A transparency or *slide*, produced by the camera, is placed at S and powerfully illuminated by an electric or lime light L, the latter produced by the combustion of a lime-stick with the aid of oxygen and hydrogen gas under pressure in the cylinders O and H. The condensing lenses, X, serve to converge the rays upon it, and a focusing lens, D, produces a real, inverted, and enlarged image I upon a screen (see Fig. 233).

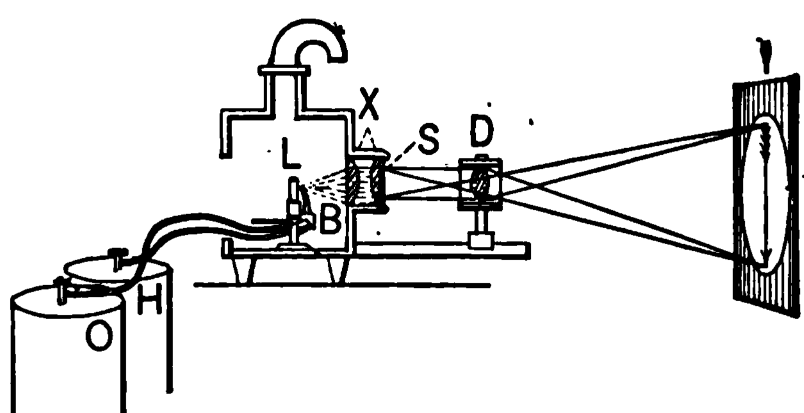

FIG. 233.—PRINCIPLE OF THE STEREOPTICON.

The position of the focusing lens D can be varied so as to bring the image on the screen. The farther the screen is away, the nearer the lens must be moved up toward the slide. If the slide be brought up to the principal focus, the image will be infinitely distant.

In the camera, the picture of the external object is formed on the slide. In the stereopticon, the slide is used to reproduce a representation of the original object. The image in the one instrument corresponds to the object in the other.

The simplest form of the stereopticon is the ordinary magic lantern, which the pupil may easily construct as follows: Make a tube for the focusing lens by winding paper round a broomstick or curtain-pole of the required diameter, applying mucilage at every turn. Set this when dry in a cigar-box furnished with a tin chimney. Use a common burning-glass for the condenser, with a tin reflector behind it and a kerosene-lamp for illumination. If photography is an accomplishment of the pupil, he can supply original illustrations for his magic lantern without limit should he further master the process of printing positive transparencies from his glass negatives. (Precise instructions for making simple slides are given in Mayer and Barnard's "Light," pages 87–89.)

FIG. 234.—COMPOUND MICROSCOPE.

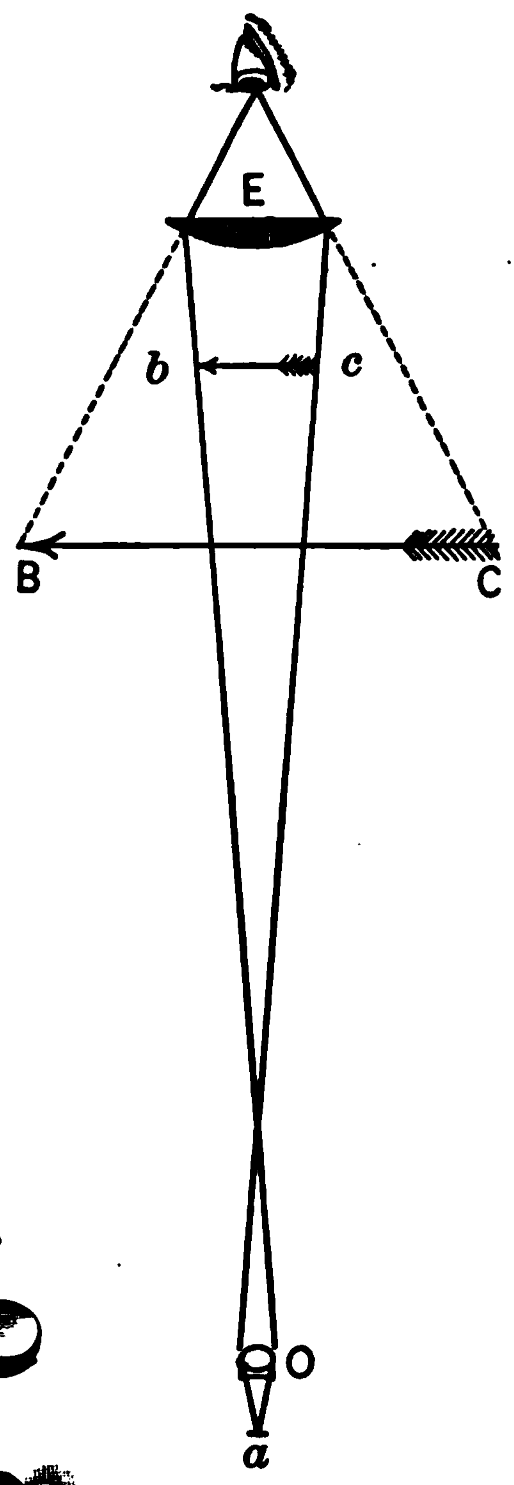

FIG. 235.—DIAGRAM ILLUSTRATING ACTION OF THE COMPOUND MICROSCOPE.

The Compound Microscope is an instrument designed to produce magnified images of objects too small to be seen with the naked eye. In Fig. 235 the object *a* is placed just outside the principal focus of a lens or combination of lenses, O, and a real magnified and inverted image, *b c*, is formed. This image is then itself magnified at B C

by means of a simple microscope E, called the eye-lens. The latter is usually mounted in a sliding tube, so that it can be properly placed with respect to the image. The lens and tube together constitute *the eye-piece.* If the magnifying power of O is fifty, and that of E four, the image seen will be two hundred times the size of life.

Chromatic aberration in the microscope is corrected by using a concave lens in combination with the object-lens O.

As in the case of the photo-micrographic camera, the microscope may be combined with the stereopticon, and illustrations of minute objects thrown upon a screen for the instruction of an audience. The electric light is now generally used for illumination, and the instrument is therefore known as the photo-electric microscope.

Astronomical Telescope.—The telescope produces a magnified image of an object which appears small because it is far away. The instrument consists of an object-glass O (Fig. 236), which forms a real, inverted, and diminished

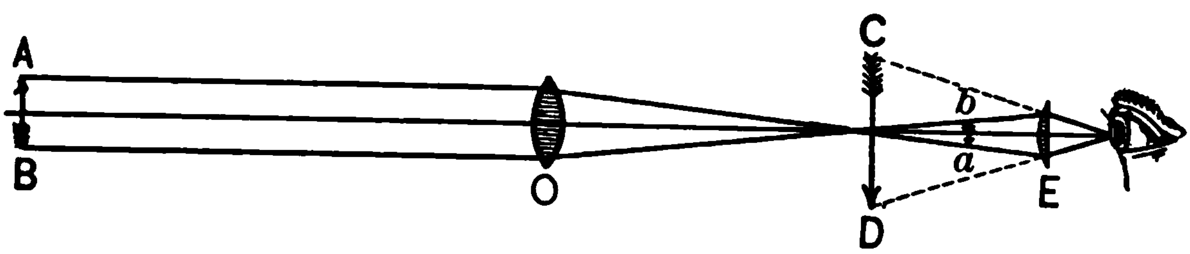

FIG. 236.—DIAGRAM ILLUSTRATING PRINCIPLE OF ASTRONOMICAL TELESCOPE.

image, *a b*, of the distant object A B. This image is viewed by means of a simple microscope E, as in the case of the compound microscope, and is thus magnified at C D.

In the terrestrial telescope, or field-glass, two additional lenses are introduced between the real image and the eye-lens, with the effect of correcting the inversion and showing the object in its natural position.

The telescope at Lick Observatory on Mount Hamilton, California (4,200 feet above sea-level), is the largest and most powerful in the

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NOTE.—A serviceable compound microscope may be obtained of Messrs. Queen & Co. at the extremely moderate price of five dollars. Provided with two object-lenses, which, in connection with the eye-piece, magnify several thousand times, it is capable of affording endless entertainment to the young investigator interested in the study of animal and plant life. Much may be learned from the use of a pocket magnifier, which is a simple microscope.

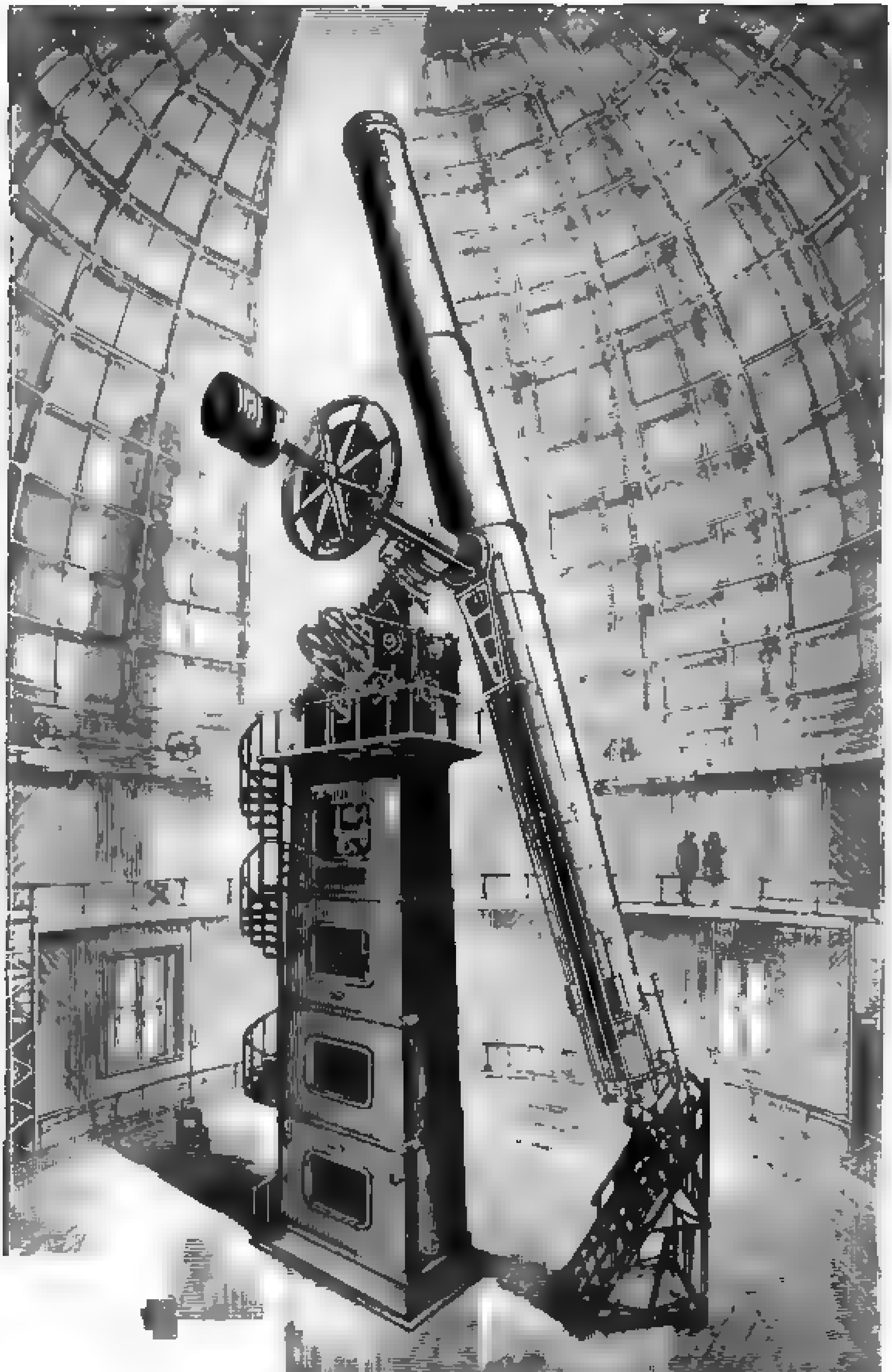


FIG. 237. THE LICK TELESCOPE.
; diameter of object-glass, 36 inches, total weight, 40 tons; magnifying power, 180 to 3,000 diameters.

world. The tube is fifty-seven feet in length, or nearly as long as the shaft of the New York obelisk. The two glasses which form the objective (a yard in diameter) cost over $50,000.

The telescope is driven by a clock inside the pier, which causes it to move so as to follow any star upon which it is directed. The rods seen along the tube are intended to clamp the telescope on its axes, and to move it when it is not quite in position. The circles are also read by means of long microscopes. All these fittings are thus accessible to the observer when standing at the eye-lens.

The Relation between Microscope and Telescope may be impressively illustrated by the pupil with the following simple apparatus:

In Fig. 238, S represents a screen of cardboard, through which a cross, with arms about half an inch long, has been cut. This cross is illuminated by a gas-jet L. O is a lens (a large pocket-lens will answer) which is placed eight or ten feet from S, and produces an

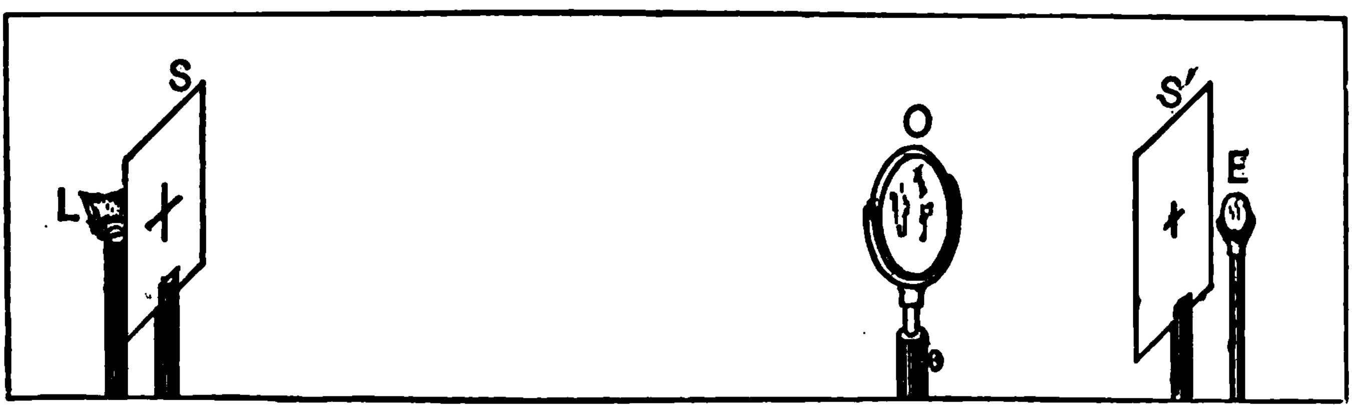


FIG. 238.—ILLUSTRATING THE RELATION BETWEEN MICROSCOPE AND TELESCOPE.

image of the luminous cross upon a screen S'. Mark the dimensions of the image in pencil, and cut it through the card. E is a lens so placed that the card S' is distinctly seen through it. Now remove S' and look through the two lenses at the card S. This arrangement constitutes a telescope.

Next let the flame and the eye-lens E change places. Focus the eye-lens on S. The image of the luminous cross in S' is now represented by the cross in S. Remove S and look at the screen S'. This arrangement is a microscope.

The focal length of the objective of a microscope is usually very short compared with that of the telescope objective.

Magnifying Power.—As seen through the telescope or microscope, an object appears a certain number of times as large as when seen from the same point with the unaided

eye. This number is called the **magnifying power** of the instrument. In Fig. 239, *c d* represents the image of the object A B. If *c d* is projected to the same distance as the object, its length would be *c' d'*. Hence the magnifying power in diameters is, in this case, $\frac{c'\,d'}{A\,B}$.

With one eye look through a telescope at a brick in a wall, and at the same time observe the wall itself with the other. The image of the brick seen through the telescope may appear as wide as ten bricks viewed with the unaided eye. Suppose A B to be a card pinned against a wall. An assistant may then mark the points *c'* and *d'* with a pencil, as directed by the observer at the telescope. A B and *c' d'* are then measured by a foot-rule. The ratio of these two lengths is the magnifying power.

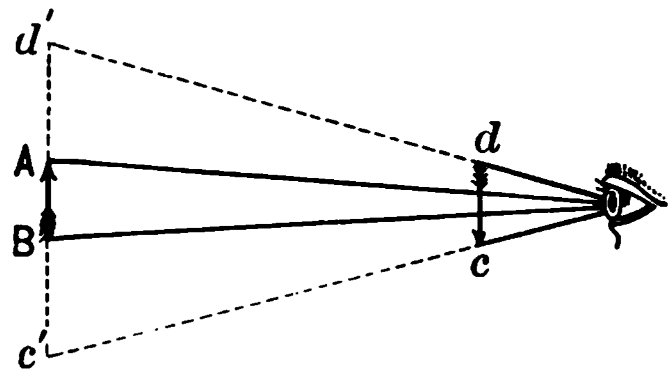


FIG. 239.—MAGNIFYING POWER.

The Stereoscope.—The views used in the common stereoscope are photographs taken from slightly different positions. The view on the left side of the card represents

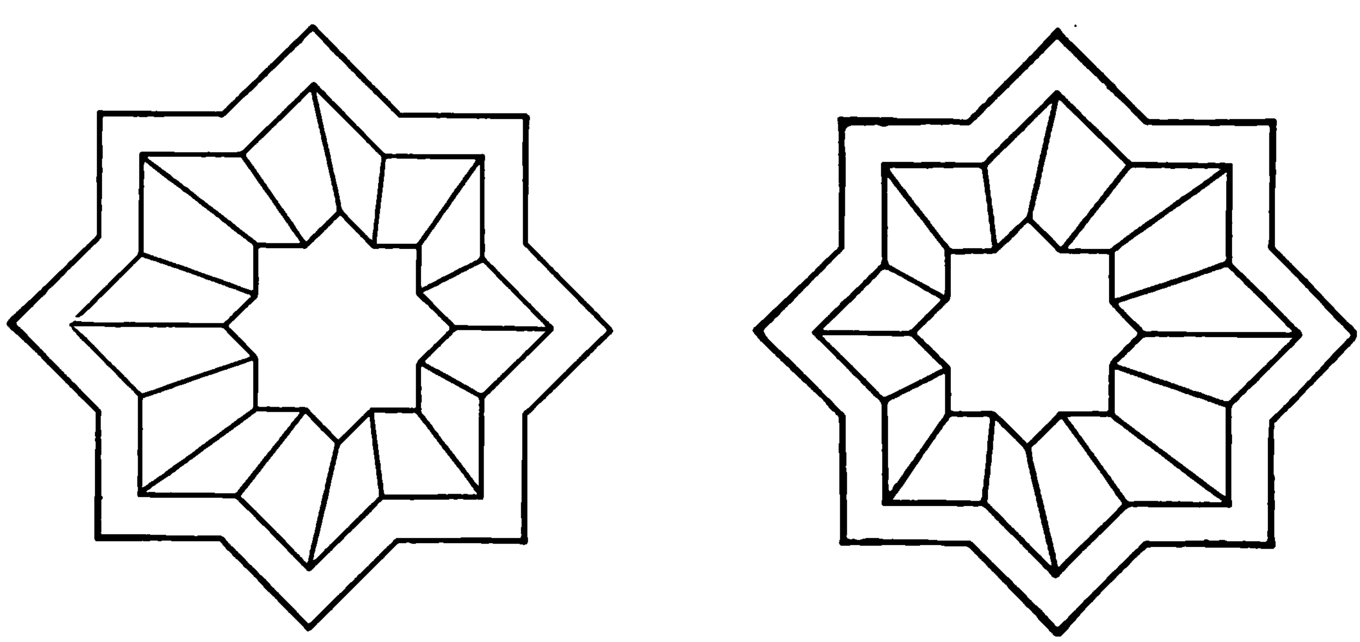


FIG. 240.—PRINCIPLE OF THE STEREOSCOPE ILLUSTRATED.

the object as seen by the left eye, while the other view represents it as seen by the right eye. Fig. 240 illustrates two such views of a pyramid.

If these figures are observed, with the eyes focused on a distant object, each one will be seen double. The two inside images can be superposed, and will then appear in relief like a solid standing up from the paper. This effect is more easily realized by holding a card or paper between the eyes and between the two pictures, so that the right eye can see only the right picture, and the left eye the left picture.

The stereoscope is designed to aid in the combination of these pictures, giving to the result a solid appearance.

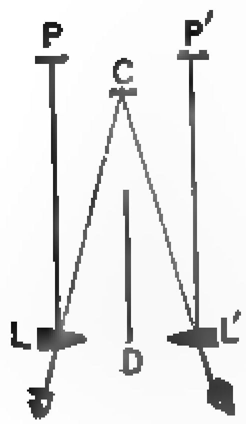


Fig. 241.—Path of Rays in Stereoscope.

The two pictures are represented by P and P′ in Fig. 241. The diaphragm or partition D prevents the right eye from seeing the left picture, and *vice versa*. The half lenses L and L′ refract the light coming from the pictures P and P′, so that it seems to have come from C.

By means of these refractors it is possible to superpose pictures which would be too large to manage with the unaided eyes. Should the two diagrams shown in Fig. 240 be copied on cards, the effect in the stereoscope will be very striking. If the two pictures exchange positions, how will the combined image appear?

Questions.—Describe the Stereopticon. Compare it with the camera. How may a simple lantern be constructed? What should be used as slides? Explain the difference between a simple and a compound Microscope; between the images respectively formed by each. What is the Photo-electric Microscope? Describe the Astronomical Telescope and the image formed in the tube. What is the character of the image in the ordinary spy-glass? How is the change effected? What can you say of the telescope at Lick Observatory? Illustrate the relation between microscope and telescope. How is the magnifying power of an instrument determined? Explain the principle of the Stereoscope.

PHOTOMETRY AND POLARIZATION OF LIGHT.

Photom′etry (*light-measuring*).—As thermometers are used for measuring heat, so there are instruments by which the intensity of light may be estimated.

The standard, in the case of light, is the flame of an English sperm-candle burning 120 grains an hour. Other

sources of light may be compared with a sperm-candle by means of a *photom'eter.*

The Bunsen photometer is shown in Fig. 242. It consists of a screen of paper S, mounted in a box B, which slides to and fro on a

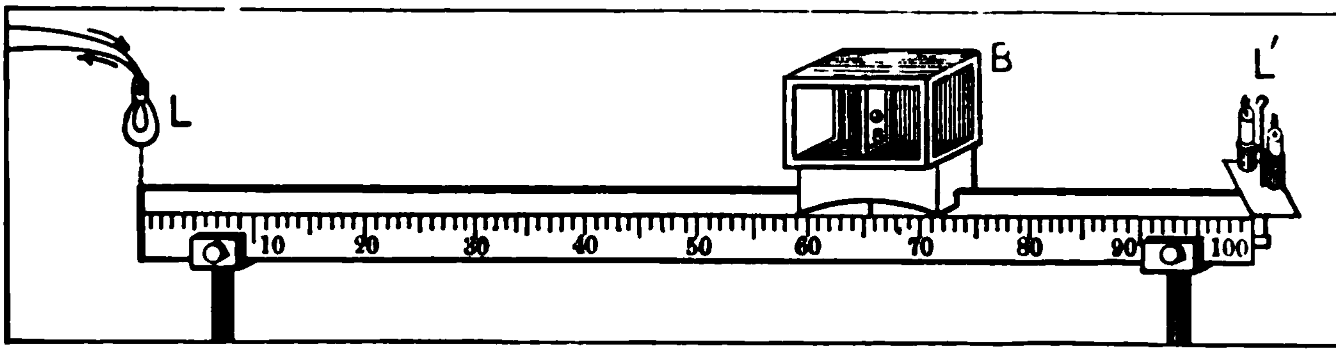


FIG. 242.—THE BUNSEN PHOTOMETER.

graduated bar. The paper screen has a central spot saturated with paraffine. One side of the screen may be illuminated by two standard candles, and the other side by a gas-flame or electric lamp. When the screen is so placed that the two sides are equally illuminated, the paraffine spot is invisible. When one side is more strongly illuminated, the spot appears dark on that side and light on the other.

If a standard candle is lighted at each end, the screen must be placed midway of the bar to render the paraffine disk invisible. If 4 or 9 candles are placed at L′ and one at L, the distance L′ B must be two or three times the distance L B to insure the same effect. The candle-power of the two lights is directly proportional to the square of the distances from the screen. The photometer should be used in a dark room having blackened walls. The room may be made of heavy paper tacked on a frame. The sliding box may easily be extemporized from a cigar-box, but the paraffine disk and sperm-candles should be ordered of a dealer in physical instruments.

The bar is usually 100 inches long and may be graduated to inches. These bars are generally graduated in candle-power direct. If the disk stands at 64 when the illumination is equal, one of the sources of light is $\left(\frac{64}{36}\right)^2$ times as strong as the other, the stronger light being the one farthest from the disk.

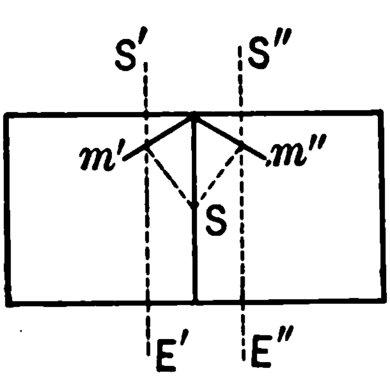


FIG. 243.

In order that both sides of the disk may be seen at once, two strips of mirror, m' and m'' (Fig. 243), are placed in a vertical position in the back of the box, so that the eyes at E′ and E″ will see the two images of the luminous spot S at S′ and S″.

In precise work, it is customary to weigh the candles before and after the test, for the purpose of determining the amount of sperm burned in a given time. Two candles should lose 40 grains in 10 minutes. If they lose 39, the two candles are $\frac{39}{40}$ of two standard candles.

If the disk stands on the average 80 inches from the electric lamp or 20 from the candles, while the two candles burn 39 grains of sperm in 10 minutes, the candle-power of the lamp would be—

$$\left(\frac{80}{20}\right)^2 \times \frac{39}{40} \times 2 = 31{\cdot}2.$$

Polarization by Reflection.—If the direct light of the sun be received upon a plate of polished black glass, it can be reflected in any direction upon the walls of a room. The character of light thus reflected is radically changed.

FIG. 244.

FIG. 245.

POLARIZATION BY REFLECTION.

The properties of the reflected ray are not now symmetrical around the ray. There are certain directions in which it can not again be reflected.

In Fig. 244, light is represented striking the lower mirror, and reflected upon a second mirror above. The mirrors admit of being turned on their horizontal axes. So long as these axes are parallel, light will be reflected, as shown in Fig. 244.

Turn the upper mirror around a vertical axis through an angle of 90°, so that the axes upon which the mirrors are mounted are crossed, as shown in Fig. 245. When the two mirrors are set so that the light on each is incident at an angle of 54° 35′, no light will be reflected from the second mirror; a black spot will appear in the center of the field of view. If the mirrors be kept at this angle, and the upper one revolved about a vertical axis, the light will grow stronger until the mirror has turned 90°. Then it begins to grow feebler until the mirror has turned another 90°, when it is again wholly extinguished.

Light which behaves in this manner is said to be *plane polarized.*

According to the accepted *undulatory theory* of light, an ordinary ray contains vibrations in many planes; but a polarized ray vibrates in a single plane. The unaided eye fails to distinguish between them. In the apparatus just described, the lower mirror is called the *polarizer*, the upper the *analyzer;* the former produces polarization, the latter makes it evident.

Light is also polarized by reflection from water. From the amalgam of an ordinary mirror the reflected beam acts like the direct sunbeam, as far as reflection from a glass plate is concerned. It has, however, been affected in a manner that the student may study in more advanced works, under the head of *circular polarization.* Reflected light from some bodies, like the metals, can not be wholly quenched by a second reflection from glass. The brightness of the beam passes through a minimum, instead of becoming zero.

Polarization by Double Refraction.—If a strong beam of light be directed through a slit in a cardboard, in front of which is a focusing lens, an image of the slit will be projected upon the screen (see Fig. 246). Interpose a polished rhombohedron of calcite (Iceland-spar) between the slit and lens. Two images of the slit will at once appear. By looking into the face from which the light emerges, it

will be observed that the beam has separated into two beams of light, each of which gives an image of the slit. That these beams separate, is clearly evidence that one of them has been refracted more than the other.

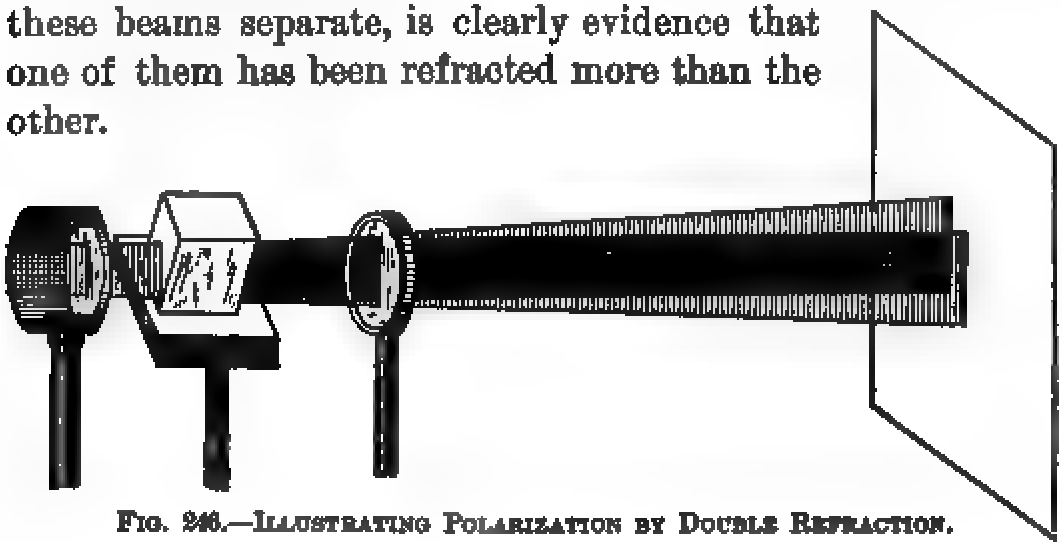


FIG. 246.—ILLUSTRATING POLARIZATION BY DOUBLE REFRACTION.

By reflecting these beams from a mirror of black glass, it will be found that they are polarized at right angles to each other. If the mirror is placed at the proper angle, one of these rays will be reflected at its maximum of brightness, and the other will be extinguished at the mirror. Turn the mirror 90° around the rays as an axis; the ray which had been extinguished will now be reflected, and *vice versa.* For intermediate positions, both images of the slit will be seen upon the walls of the room, and for the middle position they will be of equal brightness.

The distinct paths taken by rays of light in their passage through Iceland-spar may be more simply illustrated by placing a crystal of the mineral over a piece of paper containing letters. Each letter will appear double; but if the crystal be revolved, one set of letters will revolve round the other. This is more clearly shown if a black dot be used as an object. Other substances doubly refract, notably ice.

FIG. 247. PHENOMENON OF DOUBLE REFRACTION.

The Nicol's, or Single-Image, Prism is a simple contrivance for polarizing light. It consists of a rhombohedron

of calcite, which has been sawed through from one obtuse angle to the opposite, as along the diagonal plane *a c b d*, in Fig. 248. These surfaces, being polished, are cemented together with Canada balsam. The ray of common light S I, on entering the prism, is refracted into two rays. One strikes the balsam surface at an angle greater than the critical angle, and is reflected out of the side of the crystal as *o* O. The instrument thus furnishes a single beam of plane polarized light *e* E. It is more generally used than a mirror of black glass, as the ray can be kept in the same line through two successive Nicol's prisms.

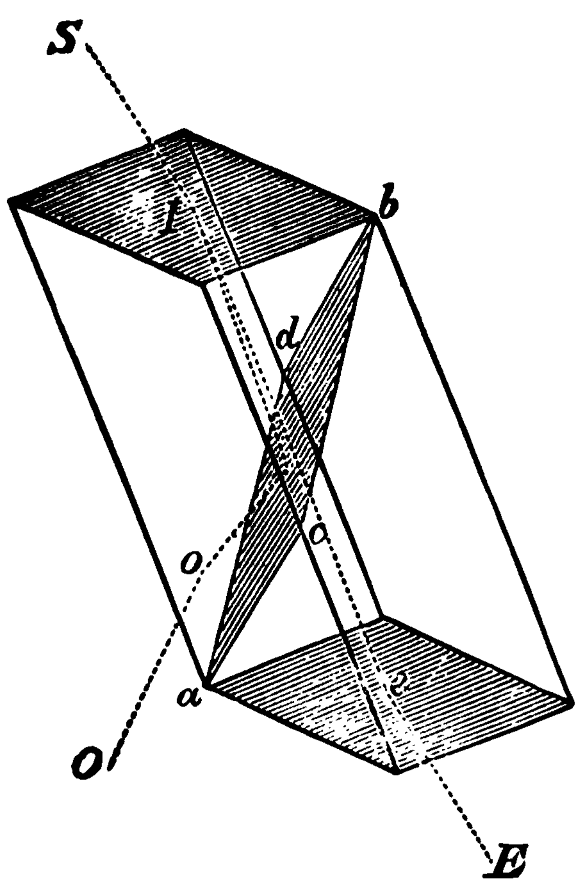


FIG. 248.—NICOL'S PRISM.

If the transmitted beam is sent through a second prism in a similar position, it will be again transmitted. Turning either prism through 90° renders the field dark. The second prism will cut off the light which the first transmitted.

Place a common window-glass over a printed page, in front of a window, and step back until the light reflected from the glass prevents you from seeing the print below. This light is polarized, and will be extinguished by a crossed Nicol. The print will then become visible. In the same way the light reflected from water may be cut off, so that objects below the surface can be distinctly seen.

Observe reflections from various objects through a Nicol's prism, turning the instrument to determine the positions of maximum and minimum brightness. Observe the sky in a similar manner.

Beautiful colors are produced by the action of polarized light. If a thin plate of mica or sel'enite (moonstone) be placed between the polarizer and the analyzer, the field will be tinted, the color depending on the thickness of the plate. A section of calcite cut perpendicular to the axis of the crystal, when viewed by divergent polarized light, exhibits

brilliant colored rings with a cross which is black or white, according to the position of the analyzer. These rings may be seen with the tourmaline polariscope, p. 366.

A cheap analyzer may be made from a bundle of thin microscope glass. Six or eight slides superposed and mounted in any convenient way will serve very well. Observe obliquely through the bundle. The color shown by selenite or mica can be seen if two panes of ordinary window-glass are held in the positions represented in Figs. 244 and 245, the selenite or mica sheet being interposed between them. All fine microscopes are now provided with a polarizing set, consisting of two Nicol's prisms, for the delicate structures of many objects can be studied only under polarized light.

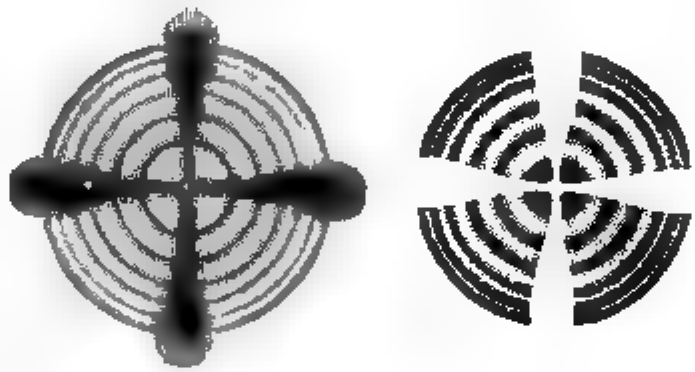


FIG. 249.—RINGS AND CROSS BY POLARIZED LIGHT.

A Polariscope may be improvised as follows: Place a plate of black glass or a piece of window-pane, G, on a base-board, which also supports a Nicol's prism at P (Fig. 250). The axis of the Nicol is mounted at an angle of 35° 25′ with the surface of the mirror. A support, S, serves for holding transparent objects which are to be examined in polarized light. A piece of ground glass, L, may be used to cut off the images of external objects. The instrument should be placed in front of a window, and the whole may be covered with a cloth to cut off light.

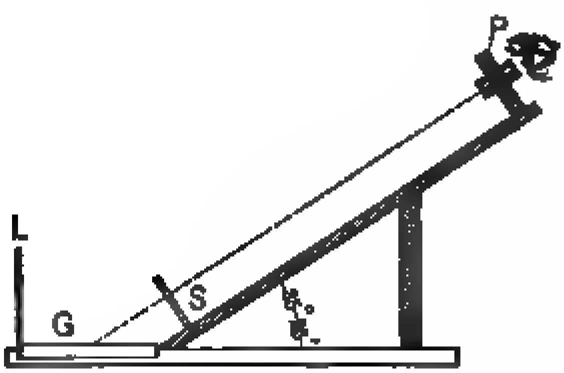


FIG. 250.—A SIMPLE POLARISCOPE.

The Tourmaline Polariscope.—The mineral tour′maline possesses in a high degree the property of polarizing

light. Two tourmaline plates, set in a mounting so that the plates can be rotated, will thus serve as a polariscope. When the plates are crossed, as shown in the figure, the field is dark. If we turn either plate 90°, we shall find the field to be bright, although colored by the tourmaline. The plates are alike, and either may be used as an analyzer.

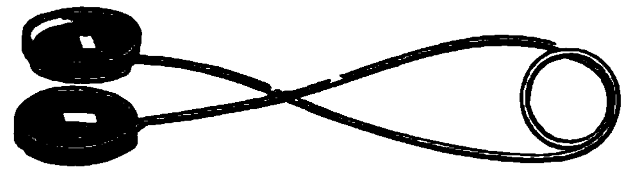


FIG. 251.—TOURMALINE POLARISCOPE.

Applications of Polarized Light.—The Saccharimeter.—The polarization of light is used in measuring the strength of sugar solutions.

In Fig. 252, *m* is a polarizing mirror which reflects a beam of polarized monochromatic light through a Nicol's prism, *a*, serving as the analyzer. The Nicol is so placed that the field is dark. If a tube, *d*, filled with sugar solution be interposed between the polarizer and analyzer, the field becomes bright. If the Nicol is rotated through a small angle, the field again becomes dark. This angle is greater, the stronger the sugar solution. With pure water the angle is zero.

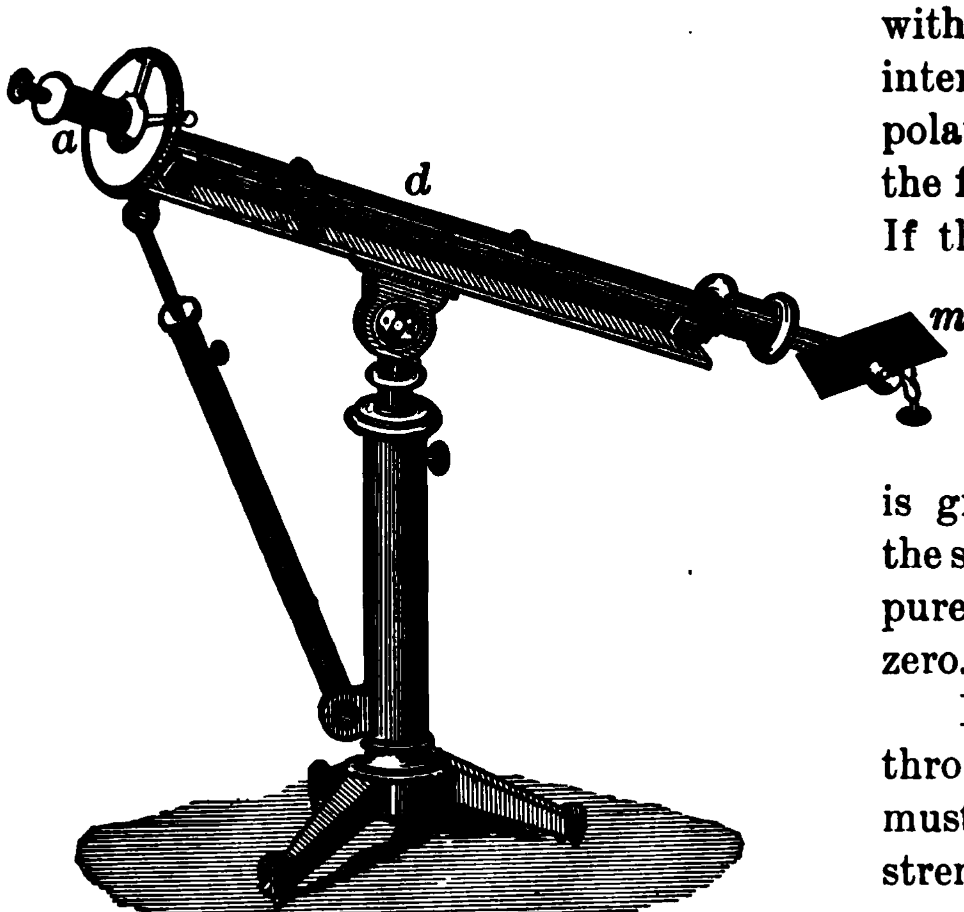


FIG. 252.—THE SACCHARIMETER.

By noting the angle through which the Nicol must be turned, the strength of the solution may be determined. Solutions of known strength are first examined in order to find the amount of sugar required to cause a rotation of 1° for a given tube.

When cane-sugar is examined, the analyzer must be turned to the right in order to produce a dark field; but, when a solution of glucose is examined, the rotation must be in the opposite direction. The mirror *m* may be replaced by a Nicol polarizer.

The principle of polarization is further applied in examining into the nature of crystals, in difficult chemical analyses, and in determining whether light from the heavenly bodies is reflected from planets and moons, or emitted by suns. The corona of the sun has been photographed during eclipses by light polarized in many planes, and thus has been proved to shine by reflected light.

QUESTIONS.—What is Photometry? Describe the Bunsen photometer. State what you understand by polarized light. Show how light may be polarized by reflection. Can the eye distinguish between polarized and ordinary light? In a polarizing apparatus, distinguish the polarizer from the analyzer.

Explain the phenomenon of double refraction. Illustrate with a piece of Iceland-spar. What is a Nicol's prism? How is it made? State how it is used; how it may render objects below the surface of water visible; how it may produce colors. Having a Nicol's prism, can you design a polariscope? Describe the tourmaline polariscope. Explain some applications of polarized light. How is it of use to the microscopist? To the chemist? To the astronomer?

APPLICATION OF THE PRINCIPLES OF REFRACTION, REFLECTION, AND DISPERSION, IN THE RAINBOW.

The Rainbow is produced by sunlight passing through drops of water, which act as prisms. It is composed of the seven prismatic colors. There are sometimes two concentric bows. The inner or primary bow shows the spectrum colors in regular order, the red being outermost. The secondary bow shows the colors in reverse order, the red being innermost. The center of the bows is determined by a line passing through the center of the sun and the eye of the observer. This line is called the axis of the bow.

Conditions of Visibility of the Rainbow.—The observer must stand with his back to the sun, and the drops which produce the bow must be in front of him.

If the sun is in the horizon, half of the complete circles will be seen above the horizon.

In the dense spray of Niagara, the rainbow is seen as a complete circle, and apparently only a few feet distant. In an ordinary rain-storm,

the part of the bow below the horizon is not usually visible in a level region, because there is not a sufficient number of drops between the eye and the immediate foreground to produce an appreciable effect.

Action of the Rain-drop.—In Fig. 253, the circle whose center is at D represents a section of a rain-drop. A ray of sunlight, S *a*, falling on the upper part of the drop, will be in part reflected; but some of the light will enter the drop. Of this light, incident upon the inside of the surface at *n*, part will pass out again into the air. The rest being internally reflected is again internally incident at *a'*. Here the same result follows as at *n*, and the light which escapes into the air proceeds to the eye at E.

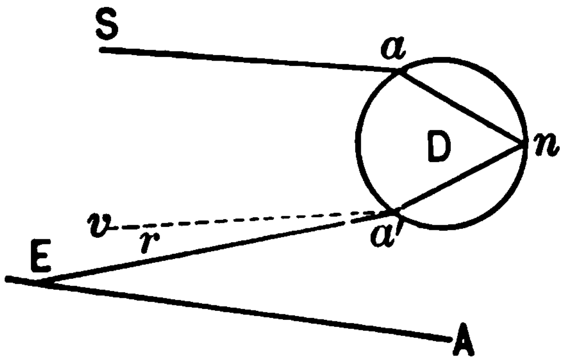


FIG. 253.—ACTION OF RAIN-DROP IN FORMATION OF PRIMARY BOW.

If this drop is so situated as to send red light to the eye, then, since they are more refracted, violet and in fact all other colors will be thrown above the eye, as in *a' v*, representing the violet ray. The drops which send violet to the eye at E must therefore lie below those sending red.

In the formation of the secondary bow, two internal reflections take place, as shown in the drops D D (Fig. 254).

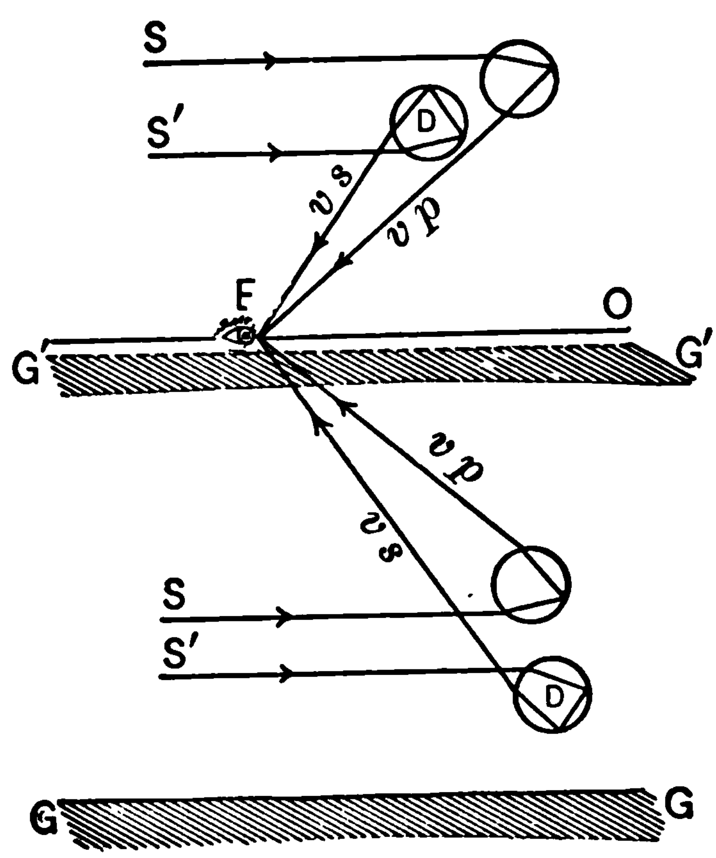


FIG. 254.—FORMATION OF SECONDARY BOW.

Here the eye, E, is supposed to be far above the ground, G G. The sun's rays, S and S', being horizontal, the sun is assumed to be in the horizon. Two rays, S, enter drops, the one at the top and the other at the bottom of the complete circular bow which would be

visible at that altitude. They are supposed to send violet light to the eye after one reflection, the rays being marked $v\ p$. The rays $v\ s$ are the violet rays of the secondary bow. The drops are represented at different distances from the eye.

If the ground were at G′ G′, then only half of the bows would be visible, unless the region immediately around the eye were filled with a dense spray, when a complete circular rainbow of the same angular magnitude might be seen. The real diameter of a bow is indefinite, as some of the drops producing it may be only ten feet from the eye, while another drop an instant later, sending the same color to the same part of the retina, may be a mile away.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

The nearest fixed star is about 25,000,000,000,000 miles away. How long is light in coming from this star to the earth ?

A cannon-ball, maintaining a constant average velocity, would require over seventeen years to traverse the distance between the earth and the sun ; how long does it take light to pass over this distance ? (See page 297.)

State the most obvious distinctions between light and heat. To what laws are both subject ? Could there really be any light without eyes ?

Why does the image formed by a lens or aperture always appear inverted, while that reflected from a mirror does not ?

When a ray passes from a rarer to a denser medium, is it refracted toward or from the perpendicular ?

It is estimated that not more than $\frac{1}{3000}$ of the sun's light reaches the surface of the earth. Why is this ?

The planet Venus is 67,245,000 miles from the sun ; Saturn is 886,779,000. How does the light received by Venus compare with that received by Saturn ?

If a ray of light from the sun is 12,350 seconds longer in reaching Neptune than Jupiter, how many miles farther from the sun is Neptune than Jupiter ?

The illuminating powers of a lamp and candle are as 10 to 1. How far from the lamp, in the straight line joining the flames, must a sheet of paper be placed to be equally illuminated by both ?

If you can just see to read by moonlight and also by a lamp 15 feet away, how much brighter is the moon than the lamp ?

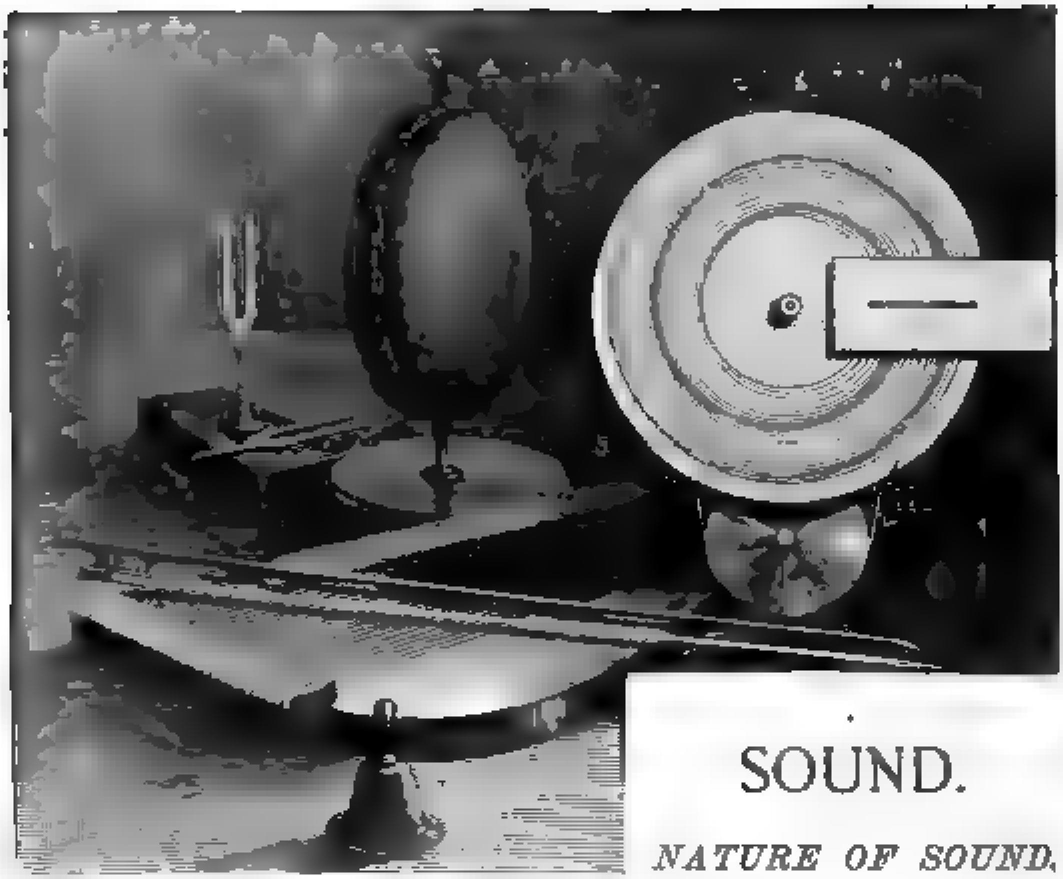
Compare the focal lengths of two lenses whose indices of refraction are respectively 1·5 and 2·4. Of what materials would they be composed ?

The index of refraction from water into turpentine is 1·11. What is the index of refraction from air into turpentine ?

What would be the result if the solar light were not composed of various colors ? How is the rainbow produced ? Explain fully the action of the rain-drop in producing the primary and secondary bow.

What colors would appear black in a room to which the sun's light is admitted through red glass ?

Why is a ball fired from a cannon invisible ? *Because it moves with such velocity that the image on the retina does not remain sufficiently long to produce an impression.* It has been photographed by the instantaneous process.



SOUND.

NATURE OF SOUND.

Acoustics is that branch of Natural Philosophy under which is studied the origin and nature of vibrations causing sounds; the transmission of these vibrations through gases, liquids, and solids; and the mechanism of the organs of speech and hearing viewed as acoustic instruments.

Sound is the sensation peculiar to the ear. It is caused by the vibration of the nerves of hearing. This vibration generally has its origin in some vibrating body, such as a bell, a string, or an organ-pipe, surrounded by the air. Between the vibrating body and the drum-skin of the ear, the air vibrates in unison with the vibrating body, and this air,

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NOTE.—Let the pupil provide himself with the articles illustrated in the introductory group above. These, in connection with the simple apparatus which he can put together in accordance with instructions given in the text, will enable him to illustrate the principles of acoustics. No. 1 is a violin-bow; 2, an A tuning-fork mounted on resonant-box, 3, a C tuning-fork; 4, a sound-lens; 5, a zither; 6, a rotator; and 7, an ordinary bell. The outfit will be furnished by Messrs. James W. Queen & Co., of Philadelphia, and Mr. Samuel Hawkridge, of the Stevens Institute, at price stated in the preface.

touching the drum-skin of the ear, causes the latter to vibrate in unison.

Mechanism of Hearing.—To the drum-skin of the ear, or membrane of the tym'panum, is attached a series of three little bones called *the hammer* (H), *the anvil* (A), and *the stirrup* (S) (see Fig. 256). The foot-plate of the stirrup is connected with an oval membrane which closes a hole in the inner ear. The inner ear is filled with a liquid, in which are spread out the filaments of the auditory nerve, or nerve of hearing. The drum-skin, vibrating in unison with the vibrating body and the air surrounding it, sends vibrations through the little ear-bones (ossicles) to the liquid and nerve-fibers in the inner ear, and the trembling of these nerve-fibers causes the sensation called Sound.

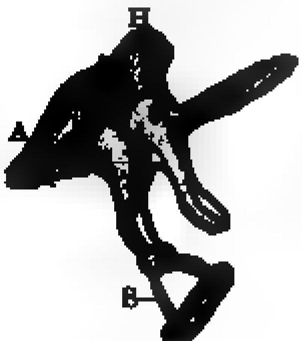


FIG. 256.—OSSICLES IN POSITION.

Fig. 257 illustrates the parts of the human ear. Waves of sound are collected by the trumpet-shaped external ear or *pinna* (1) and directed through the *auditory canal* (2, 3) to the *drum* (4). The ham-

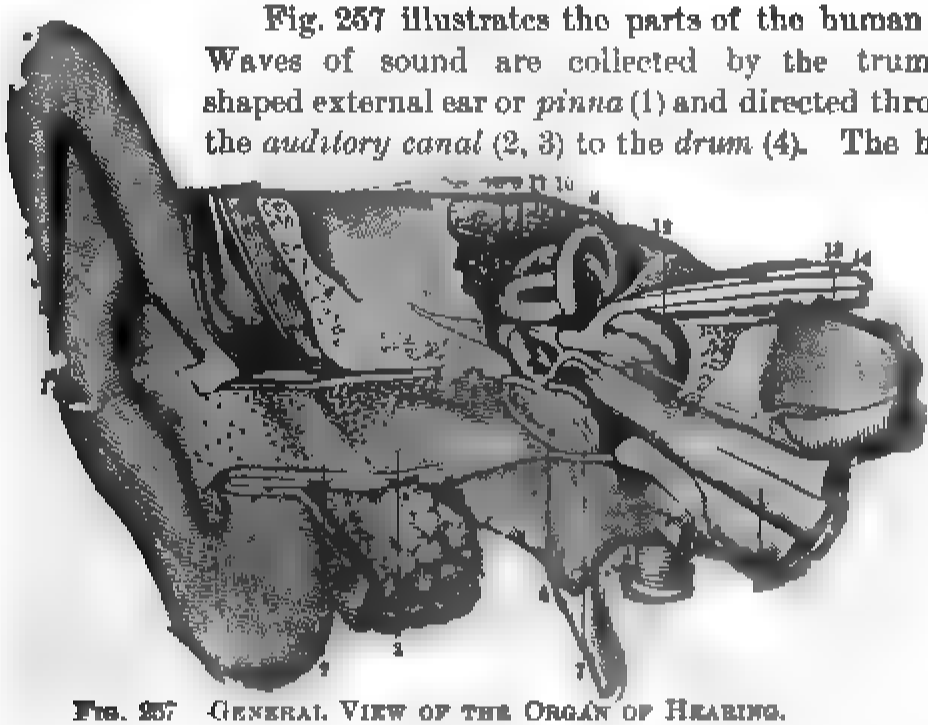


FIG. 257 GENERAL VIEW OF THE ORGAN OF HEARING.

1, pinna; 2, 3, auditory canal, with openings of wax glands; 4, membrana tympani, or drum-skin; 5, portion of anvil; 6, hammer; 7, handle of hammer applied to internal surface of drum-skin, which it draws inward; 8, Eustachian tube; 9, 10, 11, semicircular canals; 12, cochlea; 13, 14, auditory nerve.

mer-bone (6) is shown connected with the drum-skin; the stirrup-bone is attached to an oval membrane closing a hole in the *vestibule* of the inner ear. From this vestibule, the cavity opens into *the semicircular canals* (9, 10, 11), and also into a spiral cavity (12), which so resembles a snail's shell as to be called by its Latin name, *cochlea*. In the cochlea are the filaments of the auditory nerve (13, 14).

Sound implies Vibration.—To show that we have defined sound correctly, and truthfully represented its nature, we must prove—

1. That whenever we perceive a sound, some body, either a solid, a liquid, or a gas, is in vibration.

2. That the air surrounding the vibrating body is also vibrating in unison with it.

3. That the drum-skin and bones of the ear are at the same time vibrating with the vibrating body and the air.

Fig. 258.

The Vibrating Body.—Fig. 258 represents a tuning-fork mounted on a resonant-box. If we draw a violin-bow across one of the prongs of the fork, or strike it with a stick covered with leather, we hear a sound. The fork is now in vibration, for if we touch the face of one prong with a little ball of cork suspended to a fine silk fiber, we shall see the cork violently repelled from the prong, and these blows against the cork ball will be visible until the sound becomes almost too feeble to be heard. The cork pendulum will in like manner show the vibration of a bell, a finger-bowl, a plate or rod, a stretched membrane, a string, etc.

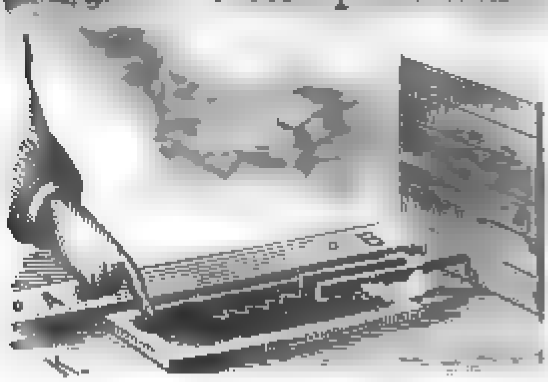


Fig. 259.—Proof of Vibration of Tuning-Fork.

Further, unscrew the fork from its resonant-box and cement to one of its prongs a triangular piece of thin copper-foil. Strike the fork with a stick, and draw along, under the tip of the

foil, a piece of glass blackened with camphor-smoke. The trace of the point of the foil will appear as in Fig. 259, showing that, while the glass was drawn along, the prong went many times to and fro in a direction at right angles to its path. If we had armed each prong with its own piece of foil, we should have had a double trace, like that shown in Fig 260. Such a trace proves that the prongs, in vibrating, approach each other and then recede, and that one prong makes the same trace as the other.

The Vibrating Medium.—If a membrane of paper or gold-beater's skin be stretched on a frame, and a few fine particles of sand be placed on it, the sand will jump up and down when the membrane is held in the air at a distance from a vibrating and sounding body. If we stretch a piece of linen paper over the mouth of a tumbler, and then cut away part of the paper till the tumbler gives forth a loud sound when the fork is brought over the opening, as shown in Fig. 261, we may place the tumbler in any part of the room, and sand on the paper will dance whenever the fork is sounded on its resonant-box, or when an organ-pipe is blown which gives the same note as the fork.

FIG. 260.—VIBRATIONS OF BOTH PRONGS REGISTERED.

FIG. 261.

If two bodies vibrate the same number of times a second, and one of them is sounded, the aërial vibrations caused by this one will set in vibration the other body, even at a considerable distance. This phenomenon is a general one, and is called *co-vibration*. It may be readily exhibited by placing two tuning-forks, which give the same note, on their resonant-boxes and at a distance of several feet from each other. If one of the forks be sounded, the other will enter into vibration.

The Vibrating Ossicles of the Ear.—In Fig. 262 are presented traces obtained by König, of Paris, on attaching a delicate bristle to the several bones of the ear. This bristle was in contact with the surface of a revolving cylinder

covered with lamp-black. When an organ-pipe or fork was sounded in the air, the bristle vibrated with the bone to which it was fastened, and these vibrations were traced by the bristle on the cylinder.

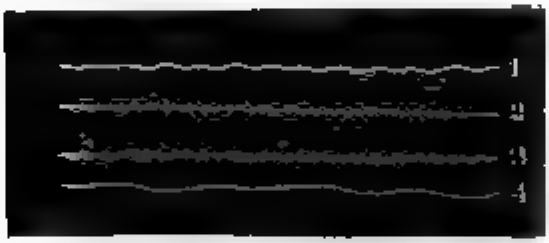


FIG. 262.—REGISTERED VIBRATIONS OF OSSICLES.

1, Vibrations drawn with a bristle attached to the hammer of the human ear; 2, 4, vibrations of two organ-pipes traced with a bristle attached to the anvil; 3, vibrations of a bristle attached to the stirrup of the ear of a goose.

The traces obtained were found to have the same number of flexures in them, in a given length, as the trace made simultaneously on the cylinder by a second fork in tune with the first. Thus it was clearly shown that the parts of the ear vibrate in unison with the sounding body, as well as with the air striking the drum-skin.

Our knowledge of sounds is wholly due to the interpretation of vibrations by the nerves of the ear. Hence a deaf-mute can have no conception of sounds. Vibrations, it is true, are *felt*, not only by the hand, but, in case of deep tones, by the whole frame. Persons born deaf may thus experience pleasure on the performance of music. *Feeling vibrations,* however, is very different from *hearing sound.*

Air is not the only Medium of Transmission of sound. If the foot of the tuning-fork be screwed into a disk of wood, and this disk placed in contact with a column of water contained in a jar which rests on the resonant-box of the fork, we shall hear, when the fork is struck, a sound caused by the transmission of the vibrations of the fork through the water to the resonant-box.

If, while bathing, you hold your head under the water for a moment, you will be able to hear distinctly a sound produced beneath the surface at a considerable distance. This proves that water is a transmitting medium.

Fish are provided with organs of hearing, which are affected only by the vibrations of the element in which they live. Such vibrations

may be communicated to the water of a stream by persons walking along the bank, and are immediately appreciated by the nerves of fishes insensible to sounds made in the air.

Further, if a long wooden rod be placed against the head, and the other end of the rod be brought in communication with the foot of the vibrating fork, we shall hear a sound caused by the passage of the vibrations of the fork through the wood, and through the skin and bones of the head, to the nerves of the ear. The conducting power of seasoned wood furnishes a ready test by which a flaw may be detected in a beam; rotten wood interferes noticeably with the transmission of sound.

FIG. 263.—THE STRING TELEPHONE.

Attach to the foot of the tuning-fork a string held between the teeth. When the string is stretched between the teeth and the fork, and the latter is vibrated, the sound of the fork will be heard. The String Telephone, or Lovers' Telegraph, illustrates, in an interesting manner, the transmission of sound by a cord. It may be cheaply made by removing the bottoms from two small tin cups and supplying their places with pieces of rubber or parchment, tightly wound on and connected with the ends of a long cord. If the cord be drawn tight, a conversation may be carried on between persons a number of rods apart, by using one cup as a mouth-piece and listening at the other, as shown in Fig. 263. Small pasteboard boxes may be used instead of the cups.

An approaching locomotive can be heard at a great distance by placing one's ear on the rails. The American Indians knew by expe-

rience the facility with which solids transmit sounds, and were in the habit of applying their ears to the earth when they suspected the approach of an enemy, or wanted a more distinct impression of any sound that attracted their attention.

Sound not produced in a Vacuum.—As sound thus implies the vibration of air or some other material substance, there can be no sound in a vacuum. A bell rung in the exhausted receiver of an air-pump can not be heard. The absence of atmosphere on the moon's surface imports perpetual silence.

To illustrate this principle simply, pour a little water into your glass flask, close the flask with an India-rubber cork having two holes, through one pass a glass rod, and by means of a piece of rubber tubing attach to the end of the rod a toy bell. Now apply heat until the water boils. The steam will expel the air, and, if you close the second hole in the rubber cork with a glass stopper, you will have a fair vacuum in the flask when the steam condenses. If the flask be now shaken, the sound of the bell will be extremely feeble, if not inaudible.

Velocity of Sound.—The vibrations causing sound are transmitted by air at a temperature of 32° Fahr., with a velocity of 1,090 feet a second. With every rise of 1°, the velocity of sound increases by one foot. Thus, at a temperature of 85° (53° above 32°) the velocity of sound in air is 1,143 feet a second. At 60° Fahr., sound travels a mile in about $4\frac{3}{4}$ seconds.

The velocity of sound in air is thus less than that of light; it is also less than that of a bullet. A rifle-ball reaches a deer before he hears the report; but the flash is seen before the bullet strikes. Water-fowl learn to dive, and wary game to dodge, at sight of the flash, and so escape. With the old flint-lock fowling-piece, the flash in the pan gave longer notice of danger.

The velocity of sound in oxygen gas, at 32°, is 1,040 feet a second. In hydrogen, it is 4,160 feet, or four times as great. As a cubic foot of hydrogen weighs only $\frac{1}{16}$ as much as a cubic foot of oxygen, it follows that the speed of sonorous vibrations through gases varies inversely as

the square roots of the weights of equal volumes of the gases, or, in other words, in the inverse ratio of the square roots of their densities.

Sound travels more rapidly in liquids and in solids than in air. The velocity of sound in water is about 4½ times as great as in air. In steel, it is about 10½ times as great.

The Velocity of Sound is the same for all Notes, whether high or low. This was shown by Biot (*be-o'*), who found that melodies played at one end of the long aqueduct of Paris reached the other end without alteration. This could not have been if the sounds composing the melodies had different rates of velocity.

QUESTIONS.—What is Acoustics? Define Sound. By what is sound caused? Explain fully the mechanism of hearing, drawing on the blackboard a diagram of the auditory canal and inner ear. What three vibrations are implied in the sensation of sound? Prove that the sounding body vibrates by an experiment with the tuning-fork; with a common bell. Why is the bell stopped from ringing by touching it with the finger. Moisten the edge of a glass finger-bowl or thin goblet, and move the finger rapidly around it; why will it give forth a musical sound? Strike your tuning-fork, and hold a card near it; why will you hear a continuous tapping? Do you know how the vibrations of both prongs may be registered? Prove that the air is in vibration when we hear a sound. Explain the phenomenon of co-vibration. What interesting experiments show that the ossicles, or little bones of the ear, vibrate in unison with the air? Explain the difference between feeling vibrations and hearing sounds.

Can you think of any causes of deafness? *Whatever interferes with the transmission of vibrations to the nerves of the ear causes deafness, as ceru'men or wax in the auditory canal, perforation of the drum-skin, or destruction of the little bones by inflammation in scarlet fever. In order that hearing may be perfect, the cavity of the middle ear, which is spanned by the three bones, must contain warm air. Nature provides for its free admission through the Eustachian* (*yu-sta'ki-an*) *tube* (see Fig. 257, No. 8), *which connects the middle ear with the throat.* Why, then, is temporary deafness produced by a cold? Can you think of a reason why exposure to loud noises may be injurious to hearing? Why, boxing the ears? Surf-bathing? A severe blow on the head?

Is air the only medium of transmission of sound? What evidence is there that water transmits vibrations? Do fish hear? How? Describe an easy method of detecting a rotten spot in a wooden beam. What is the string telephone? Why can you hear a train coming by placing your ear on the rail, when the air conveys no perceptible sound of its approach? How can you show that sound is not transmitted in a vacuum? State the velocity of sound at 50° Fahr.; at 70°. What familiar example can you give to prove that sounds of all kinds travel at the same rate? Do all substances transmit sound with the same velocity? What is the velocity of sound in water? In steel? Standing in a lumber-camp, at some distance from a wood-chopper, I hear the blow of his axe 2¼ seconds after I see the chips fly. Suppose the temperature to be 34° Fahr., how many rods am I from the chopper?

PROPAGATION OF SOUND.—WAVE-MOTION.

Principle of Transmission.—Before beginning the study of the nature of sound transmission, it will be necessary to understand the following experiment with glass balls, showing how vibrations travel through elastic bodies. Fig. 264 represents a wooden railway about 6 feet long. It

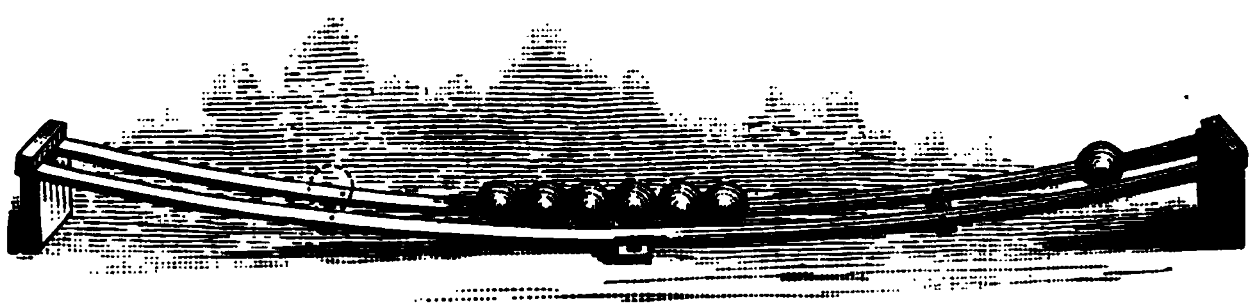


FIG. 264.—ILLUSTRATING HOW VIBRATIONS TRAVEL THROUGH ELASTIC BODIES.

is made of thin strips of pine, placed side by side, about an inch apart, and joined by cross-pieces. The cross-piece at the center is screwed down to the table, and the ends of the elastic slips are then raised on blocks. Place a few large glass marbles in the middle of this curved railway, and then bring one to the end and let it roll down against the others.

The marbles will remain stationary except the farthest one, which will fly up the incline toward the other end of the railway and then roll back again, causing the first marble to ascend the incline on the right. This action will continue till friction brings the marbles to rest.

The marbles employed in the experiment are very elastic. This is proved by rubbing a slab of stone with a mixture of oil and red lead and placing a marble on it. The marble will be marked by a small circle of red; but if we allow it to fall on the stone, a much larger circle of red will be made, showing that the marble must have flattened when it struck, as it evidently touched a larger surface of the stone.

The first marble rolls down the railway and strikes the second, which is thus flattened between 1 and 3, as shown in Fig. 265. Marble No. 2 at once springs back into its former spherical figure, and in so doing brings No. 1 to rest and flattens No. 3, as shown in Fig. 266. Marble No. 3 then springs to its former spherical figure, bringing to

rest No. 2 and flattening No. 4. Thus each marble receives the blow of the marble behind and passes it on to the one in front, and we have a series of contractions and expansions running rapidly through the

FIG. 265.

FIG. 266.

row. When the last marble is flattened, it at once expands, bringing the one behind it to rest, and, having nothing in front, it is shot up the railway.

Compression and Expansion in a Tube.—Similar actions take place in successive portions of air as sonorous vibrations traverse them. In Fig. 267, a long tube, *d f g e*, is open at *f g* and closed at the other end by a piston *a*, which can be moved forward and backward in the tube. Suppose the piston *a* to move quickly forward to the position *b*; then, if the air were inelastic and incompressible, a portion of the column of air equal to that from *a* to *b* would be pushed out of the end of the tube at *f g*. As the air is elastic, it is compressed by the forward motion of the piston; but only to a certain distance beyond *b* is it so compressed *at the instant the piston has reached b.*

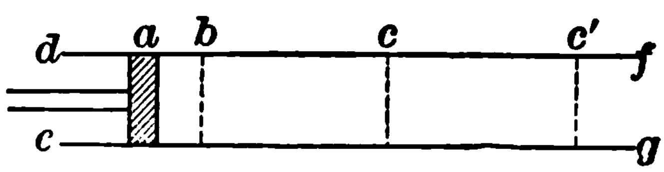


FIG. 267.—TRANSMISSION IN A TUBE.

The length *b c* of this compression is found thus: The compression can travel only as fast as the velocity of sound, which at 40° Fahr. is 1,100 feet a second; so that if the piston takes $\frac{1}{100}$ of a second to go from *a* to *b*, the length of the compressed air, *b* to *c*, is $\frac{1}{100}$ of 1,100, or 11 feet. If the piston takes $\frac{1}{1000}$ of a second to go from *a* to *b*, then the depth of the compressed air is $\frac{1}{1000}$ of 1,100 feet, or $1\frac{1}{10}$ feet.

At the moment the piston *a* reaches *b*, we have compressed air in the tube from *b* to *c*. This compressed air is elastic—like a bent spring, or one of the glass marbles used in the previous experiment; it at once expands, and in the same time (assumed to be $\frac{1}{1000}$ of a second) that was occupied in its compression. It presses against the interior of the tube and against the piston at *b*; but these do not yield. It also presses and at the same time expands in a forward direc-

tion, toward the mouth of the tube, and in the next $\frac{1}{1000}$ of a second it has by this expansion compressed another mass of air, c to c', equal in length to b c. In compressing the column c c', the air in the column b c expanded to its natural volume. The column c c' next expands as did the column b c. But it can not expand backward, because the column of air b c has expanded *with rapidity* to its natural volume in compressing c c', and therefore tends by its momentum (like a swinging pendulum) to expand still further—which action just balances the backward expansion of the air in c c', so that the column of air b c now acts like the solid piston against the column c c'. Thus the compression is sent through the air of the tube with a velocity equal to that of sound, and by a series of actions similar to those which took place in the row of glass balls in the previous experiment.

If we now suppose the piston to move in $\frac{1}{1000}$ of a second from b back to a, the air from a to c will be rarefied, and the actions following will be similar to those which took place with the column of condensed air, only a pulse of rarefied air will now travel through the tube instead of one of condensed air.

The Effect of Compressing Air is to bring its molecules nearer together, while rarefaction separates them. Hence, if we imagine the piston to vibrate regularly from a to b and back from b to a, like a pendulum, or as the prong of a tuning-fork really does, we shall have the molecules of the air in the tube making short vibrations forward and backward, each molecule having the motion of a pendulum.

If the ear be placed at the mouth of the tube, we shall hear a musical note corresponding in sound to that of a fork making 1,000 vibrations a second.

Sound-Waves in the Air.—If instead of a piston moving to and fro in a tube we have a tuning-fork or other musical instrument vibrating in the open air, the condensation and rarefaction of the air will not be confined to one direction, as in the tube, but will spread all around; so that we shall have spherical shells of compressed and rarefied air continually following one another, as they expand outward in regular order and motion, like the outward movement of circular water-waves around the place where a pebble has been dropped into a pond.

The depth of air embracing any condensed, and the adjoining rarefied, shell of air, is called a *sound-wave.* This sound-wave is entirely different from a water-wave, in which the water vibrates *up and down* in a direction perpendicular to that of the wave's progress. In a sound-wave the vibratory motions of the air are not perpendicular to, but *in the same direction as*, the direction of motion of the sound-wave.

To represent a Sound-Wave, a curve is used called the *sinusoidal curve* (see Fig. 268). In this figure, the line A B, which is the axis of the curve, represents the direction of the sound vibrations. The lengths of lines drawn perpendicularly from this axis to any point of the curve represent the amount of compression or of rarefaction of the air. Thus, at the points A, C, and B, the air is neither compressed nor rarefied. At *h* the length of the line *g h* represents the amount of compression, while at *f* the length *e f* represents the amount of rarefaction—lengths above the line being assumed to stand for compressions, and lengths below the line for rarefactions. The whole length A to B is a wave-length, while the length A to C, *j* to *k*, or C to B, is a half-wave length.

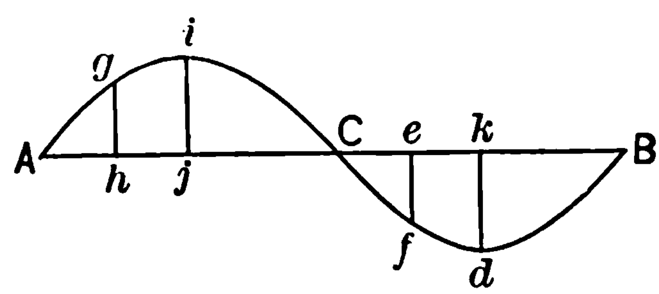
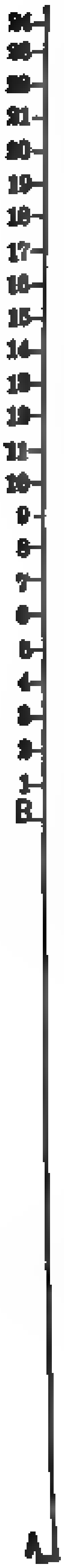


FIG. 268.—REPRESENTATION OF A SOUND-WAVE.

Although the nature of a sound-wave has been known since the time of Newton, and although this curve representing its nature has been used during almost as long a period, yet many have confounded the curve—a mere symbol—with the sound-wave itself, and have been led into gross errors by supposing a sound-wave to be composed of waves shaped like this curve and progressing through the air with heaps and hollows like the waves of the ocean.

The Nature of a Sound-Wave, and the manner in which it travels through an elastic medium, are nicely represented in an ingenious apparatus invented by Crova. In



the illustration on page 370, is represented (No. 6) a cardboard disk mounted on the axle of a rotating machine. Upon this disk are drawn 24 circles of different diameters, having their centers on the smaller circle C, shown in Fig. 269.

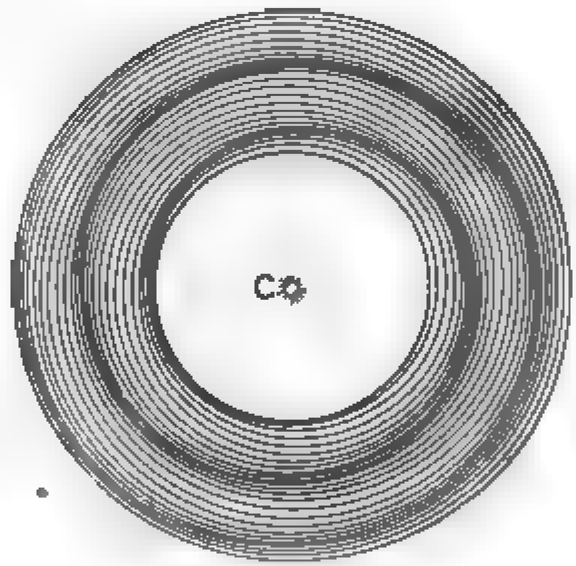


Fig. 269.—Crova's Disk, ½ size.

These circles are drawn as follows: Around the center of the disk, describe the small circle C (Fig. 270) and divide its circumference into 12 equal parts. Draw the line A, B, 24. Take the length A B with dividers, having a drawing-pen with India-ink in it, and, placing the point of the dividers on division 1 of the small circle, describe on the cardboard disk a circle having a radius of A B. Then take a radius A to 1, and with center 2 on small circle describe another circle. Then with radius A 2 and center 3 on small circle, describe on the cardboard a third circle, and so on, taking radii successively greater by one division on the scale A 24, and drawing circles with centers on successive points of the circle C.

A piece of cardboard having a slit cut out of it (shown in No. 6, page 370) is placed horizontally so that only short lines of the circles are seen in the slit. On rotating the disk, these short lines, which stand for molecules of the air, will be seen to move backward and forward like so many little pendulums, producing in the row of lines a horizontal, worm-like movement. This movement causes a wave to appear at one end of the slit, move along, and disappear at the other end, by the *successive* crowding together (condensation) and separation (rarefaction) of the row of dots.

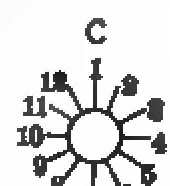


Fig. 270.

If we examine closely the cause of this progressive wave-motion, we shall see that each dot moves only backward and forward; but as these motions of vibra-

tion are successive and not in unison, it is evident that we have a series of condensations of the dots, alternated with a series of separations or rarefactions, following one another in a uniform movement and order, and progressing along the slit. This pictures to the mind the motion of successive condensations and rarefactions in the air as sonorous vibrations pass through it.

In an Experiment described by C. J. Woodward, of Birmingham, England, the same progressive motion of the condensations and rarefactions of a sound-wave is obtained directly from the vibrations of small pendulums.

A row of pendulums of equal length is suspended from a rod, A B (Fig. 272). In order to start the pendulums, the bobs are placed against an angular-shaped board F C D, the rod being held in a plane slightly behind the plane of the board. If, now, the rod and pendulums are raised together vertically, l will first swing, then k, and so on, till all are free. When the pendulums are raised with a uniform velocity, then each pendulum starts at an equal period of time after the one that is next to it. The result is that a wave-motion is seen to run along the line of bobs as they vibrate to and fro.

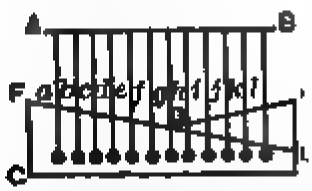


FIG. 272.—WAVE-MOTION ILLUSTRATED.

Such an arrangement has been used to illustrate wave-motion, as each bob moves with harmonic motion—i. e., a motion like a pendulum's; but it does not illustrate directly those compressions and rarefactions whereby sound is propagated. A change of position of the rod, however, at once makes it do so. If, while the pendulums are vibrating, the rod from which they are suspended be turned in the horizontal plane through a right angle, the direction of the swing of each pendulum is not changed, and all the pendulums swing in the same plane. This will become clear from Fig. 273, where the pendulum-bobs viewed along O X appear to trace out wave-motion. The relative position of the bobs, after the rod which supports them is turned through a right angle, is shown along O Y. The motion then illustrates mechani-

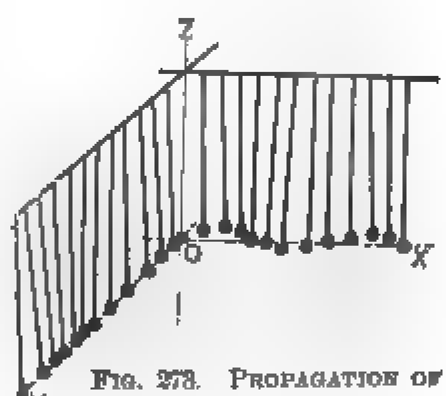


FIG. 273. PROPAGATION OF A SOUND-WAVE.

cally those movements of air particles which, when in compression and rarefaction, propagate a sound-wave.

Pendulums made of bullets 1·5 centimetres in diameter, suspended from threads 30 centimetres long, were found to answer the purpose.

Interference of Sound.—If a condensed half-wave meets a rarefied half-wave, and these half-waves have the same length and the same extent of vibratory motion, then they must neutralize each other's action in that part of the air where they meet, and no motion results from their combined action. The reason of this is that, while the condensed half-wave tends to force the molecules of air closer together, the rarefied half-wave tends with an equal energy to separate them; so they remain at rest, and at the place of meeting of the half-waves there is no sound. This fact is made apparent in many experiments.

The trace obtained simultaneously from the two prongs of a vibrating fork (see Fig. 260) shows that these prongs move apart and then draw together, each making the same number of vibrations in the same time. When the prongs of a fork approach each other, the air is condensed in front of the space between the prongs, and rarefied in front of the flat faces of the prongs; and when the prongs separate, the air is rarefied in front of the space between the prongs, and condensed in front of the flat faces of the prongs. Thus we have at the same instant four equal actions, whose combined effect on the air is shown in Fig. 274 when we look down upon the tops of the prongs *c c*.

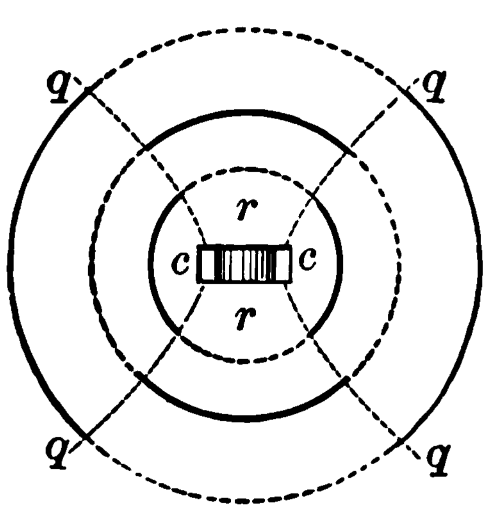


FIG. 274.—INTERFERENCE OF SOUND ILLUSTRATED BY A VIBRATING TUNING-FORK.

Imagine the prongs swinging away from each other in their vibration. Then the action of the faces *c c* on the air is to condense it, and this condensation tends to spread all around the fork; but by the same movement of the fork the space *r r* between the prongs is enlarged, and hence a rarefaction is made there, and this rarefaction also tends to spread all around the fork.

Now, as the condensation produced at *c c* and the rarefaction at *r r* spread with the same velocity, it follows that they must meet along the dotted lines *q q q q*, drawn from the edges of the fork outward, and on the planes indicated by these dotted lines, there will be no motion of the air. This fact is shown by slowly rotating the fork around its length as a vertical axis, while the fork is held near the ear. Whenever the planes *qqqq* are opposite the ear, there is silence. In other positions of the fork, sound is heard. In one rotation of the fork, there will be four places of silence.

Fig. 275.—Illustrating Interference.

The same fact is also apparent on rotating the fork over a large tumbler whose mouth is partly closed by a piece of glass. The size of the opening in the tumbler is previously so adjusted that the air in the tumbler strongly resounds to the vibrations of the fork. This experiment is shown in Fig. 275.

If we adjust the openings in two wide-mouthed bottles to resound to the fork, and then arrange the bottles and fork as shown in Fig. 276, we shall have silence when the fork is so placed that each time a condensation enters one bottle a rarefaction enters the other, or *vice versa*.


Fig. 276.—Interference of Sonorous Vibrations.

Beats of Sound produced by Interference.—Interference of sound is

also produced when two sounds fall at the same time on the ear, and one of these sounds is slightly flatter or sharper than the other. This phenomenon is always observed when two organ-pipes, forks, or any two musical instruments are slightly out of tune. The experiment is readily made with two forks which, previously in tune, are put out of tune by loading the prong of one with a small piece of wax and thus flattening its note. This decrease in the frequency of the vibrations of the loaded fork makes it give wave-lengths in the air which are longer than those given by the unloaded fork.

The velocity of the sound-waves proceeding from each fork is the same; but, as the waves are of different lengths,

FIG. 277.—TWO SERIES OF WAVES ILLUSTRATING BEATS AND INTERFERENCE.

it follows that at a certain instant the condensation in two waves, one from each fork, will reach the ear at the same moment. Their united action will produce a sound greater than that given by the vibration of either fork alone, and consequently we hear a louder sound. The same increase in loudness occurs when rarefactions in the two sounds fall together on the ear; but just between these periods of increased loudness there is an instant when the sound becomes very feeble. These actions give to the sound a thumping character called *beating*.

Fig. 277 explains the action of the two series of sound-waves on each other. The longer waves are indicated by the full line; the shorter, by the dotted line. These waves are going from A to B. An ear at B, as implied in the figure, is receiving a condensed half-wave from one source of sound, and a rarefied half wave from the other. A very feeble sound is the result; but when by the forward motion of the

waves the place C reaches the ear, an intense sound is heard, for the two half-waves of the sounds are here acting together.

Reflection of Sound.—Like light and radiant heat, sound is reflected, and in such a manner as to make the angle of reflection equal to the angle of incidence. Spherical mirrors may be used to prove the principle. Determine the point to which rays of light converge if transmitted from some distant source of illumination to a mirror, and reflected therefrom. Substitute a watch for the light, and hold the ear at the point of convergence. The ticking will be heard distinctly, as if it came from the mirror, instead of the watch. The wet sails of ships, when bellied by the wind, have been known to reflect, to ears that happened to be at their foci, sounds produced at great distances.

Apartments in which reflections are produced by the walls are called Whispering Galleries. The dome of St. Paul's, London, and that of the national Capitol, furnish examples of modern whispering galleries. One of the most remarkable structures of this kind in ancient times was the Ear of Dionysius, a dungeon so called from the tyrant of Syr'acuse, and constructed in such a way that by stationing himself at a particular point he could overhear the unguarded words of his prisoners.

Echoes are merely repetitions of sounds by reflection from walls, mountain-sides, etc. The interval that must exist between the sound and the echo may easily be determined if the distance of the reflecting surface is known. Thus, for a distance of 112 feet, the interval at 62° Fahr. is equal to 112×2 (the entire distance traveled by the direct and reflected sound) divided by 1,120, the velocity of sound at that temperature of the air, or one fifth of a second.

If we assume that five syllables can be pronounced rapidly in a second of time, then it is evident that at distances less than 112 feet there can be no distinct echo, even of a single syllable; the reflected sound mingles with the direct sound of the speaker's voice, and often confuses his utterance. This is noticeable under stone arches and in large unfurnished rooms. The echoes of a room are modified or removed by furniture and hangings; the presence of an audience in a

theatre or church will quench sound-waves and thus destroy disagreeable reverberations, for sound is absorbed like light and heat. The same sound may be repeated more than once. There are echoes that repeat a syllable twenty and even thirty times. Mountain-regions afford numerous examples of multiple echoes.

The property possessed by long tubes of conveying sound accurately, is due to repeated reflection. The waves of sound, being reflected from the interior of the tubes, are prevented from dispersing as in the open air (see page 380), and hence are but slightly diminished in loudness. The French philosopher Biot found that he could, without raising his voice, converse through an empty pipe three fifths of a mile long. This fact has been turned to account in many ways; the common speaking-tube is familiar to all. The short speaking-trumpet, however, does not act by reflection, but is thought to owe its effect partly to resonance and partly to the vibration of its flaring bell, or pavillon.

Ear-Trumpets, used by deaf persons, concentrate and reflect vibrations to the interior of the ear, and thus render audible, sounds that could not otherwise be heard.

The outer part of the ear is itself of such a shape as to collect the sound-waves that strike it and reflect them to the membrane within. To enable them to hear more distinctly, we often see persons putting up their hands behind their ears so as to form a concave reflecting surface. In this case, the hand acts somewhat on the principle of the ear-trumpet. Instinct teaches animals to prick up their ears when they want to catch a sound more clearly.

Au′diphones are instruments designed to collect sound-waves and transmit the vibrations to the nerves of hearing through the bones of the head. They sometimes have the form of a fan when intended for ladies' use, and are pressed against the upper teeth.

Refraction is a property of sound. To prove the refraction of sound in passing from one conducting medium to another, a lens 12 to 18 inches in diameter has been constructed by stretching and securely fastening thin sheets of India-rubber on a wide grooved brass ring, and inflating the cavity between them with carbonic acid or some other gas (see No. 4, page 370). The ticking of a watch suspended on one side of the sound-lens can be distinctly heard at the

corresponding focus on the other, while almost inaudible between the two points. This could not be so unless the sound-waves from the watch, in passing through the lens, were bent toward its axis.

Sound is also diffracted—that is, the sound-wave is bent round obstacles in its path, like houses, etc., which, however, tend to "shade off" the sound, or produce an ill-defined *sound-shadow.* The diminished intensity in the sound of a railroad train as it enters a cutting is due to the fact that the observer is in such a shadow. In the acoustic shadows cast by buildings, the air-shocks attendant upon explosions are sensibly modified.

QUESTIONS.—Explain the nature of the Transmission of Sound by means of the experiment with the elastic marbles. By what are the sounds ordinarily heard transmitted? Describe compression and expansion as illustrated in a glass tube. Explain condensation and rarefaction, and state the effect of each on the molecules of air. Strike your tuning-fork and hold it near your cheek. Why will you feel little puffs of air? Now, describe accurately a sound-wave and compare it with a water-wave. Can you represent a sound-wave on the blackboard, showing how the condensation and rarefaction constituting it are produced? Construct a Crova's disk, mount it on your rotator, and illustrate the nature of a sound-wave, and the manner in which it is propagated. Describe a more recent experiment which aptly illustrates the same principle.

What is meant by the Interference of sound? How is it produced, and how can it be rendered apparent? Why are there four places of silence in one rotation of a vibrating tuning-fork? How can this be proved with the fork, and a common tumbler partly closed by a piece of glass? Suggest another illustration of the interference of sonorous vibrations. What are *beats* of sound, and how are they produced? Under what circumstances may the phenomenon be observed? Draw a figure explanatory of the action of two series of sound-waves on each other in producing beats and interference.

How can you illustrate the Reflection of Sound? Are woven fabrics good reflectors? *No, because they are pervious to sound.* What are whispering-galleries? Define Echoes. What conditions cause single echoes? What, multiple echoes? On what does the number of syllables repeated depend? When is there no perceptible echo? Why do the echoes of an empty building disappear when it is filled with people? Explain the principle of the speaking-tube; of the speaking-trumpet; of the ear-trumpet; of the audiphone. Why do deaf persons place their hands behind their ears? Why do animals change the positions of their ears? Illustrate Refraction of sound; Diffraction. In arctic regions, persons separated by more than a mile of frozen water have conversed with ease; can you suggest a reason? *In such cases, the air is homogeneous, and offers no obstacle to the free transmission of sound-waves.* Masses of unequally heated air enfeeble sound, the waves being broken up by refraction. Why, then, can sounds often be heard farther at night than by day?

NATURE OF VIBRATIONS.

Vibrations of Strings.—If we take hold of a stretched string (A B, Fig. 278) and pull it out of the straight line A B to C and then let it go, the string will vibrate, swinging from C to D and from D to C, until the energy of its motion is given up to the air, and to the points A and B between which it is stretched.

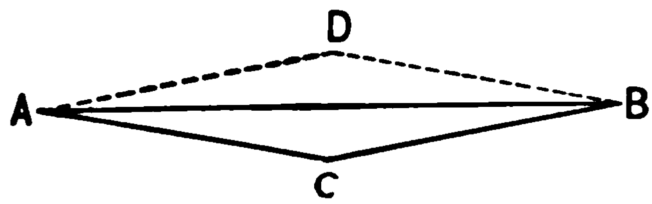


Fig. 278.—Vibration of String.

The cause of this vibration is the successive stretching and relaxing of the string; for, evidently, when it is pulled to C, the length A B has become A C + C B, which is longer than A B.

The laws which govern the vibrations of strings, wires, catgut, etc., are as follows:

1. The force with which the string is stretched remaining the same, the number of vibrations in a given time are inversely as the length of the string. Thus, strings of lengths 1, 2, 3, 4, will have 1, $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$ the number of vibrations in the same time; while strings of lengths $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, will vibrate 2, 3, and 4 times as rapidly as the string of the length 1.

2. In strings of the same substance and length, and stretched with the same force, the vibrations will be inversely as their diameters. A string 3 feet long, having a diameter of $\frac{1}{50}$ inch, will vibrate twice as many times in a second as a string of the same length and $\frac{1}{25}$ inch in diameter.

3. In strings of the same length and of the same diameter, the number of vibrations varies as the square root of the stretching force. Thus, if a string be stretched with forces of 1, 4, 9, 16, 25, the number of its vibrations a second will be as 1, 2, 3, 4, 5.

4. The number of vibrations will be inversely as the square root of the density; or, what is the same, if strings

equally stretched and of the same length and diameter weigh respectively 1, 4, 9, 16, 25, the numbers of their vibrations per second will be as 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, of the string having the weight of 1.

The Sonometer.—These laws have been determined by experiments with the Sonom'eter (Fig. 279), a long resonant-box, M N, having two bridges, B and B′ near its ends. The string, gut, or wire, is attached to the pin P, and stretched between the two bridges by passing it over the pulley H and hanging to its end the weight W. A scale on the top of the box gives the length of the string between the bridges. On vibrating the string by plucking it at its center, we hear a definite musical note, which rises in pitch as we shorten the string by sliding the bridge B′ toward B.

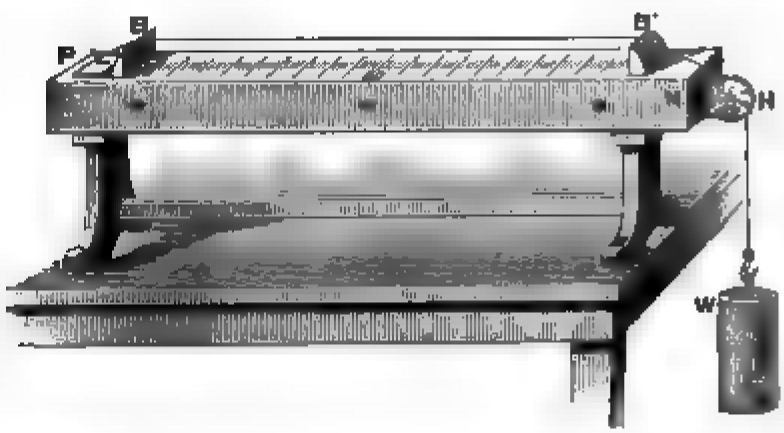


Fig. 279.—The Sonometer.

If we move B′ to one half the distance B B′, and then vibrate the string, we hear a note which is the higher octave of the note given by the whole length of the string. As we shall see farther on, the octave of a note is given by doubling the frequency of its vibrations. Thus, half a string stretched with the same force vibrates twice as many times a second as the whole length. If we sound one quarter of the string, we get the second octave above that given by its whole length. This implies that when one quarter of the string is vibrated, it makes four times as many vibrations a second as its whole length.

The second, third, and fourth laws, are proved by vibrating wires having different diameters and stretched with various weights, or having the same length and diameter but differing in weight.

The Harmonics given by a Vibrating String.—Fig. 280 represents a thin wire stretched between bridges A

and B. Place the beard of a quill at n' (in the top figure) and draw a violin-bow across the wire near v. Then lift the quill from the wire. We now see the wire vibrating as

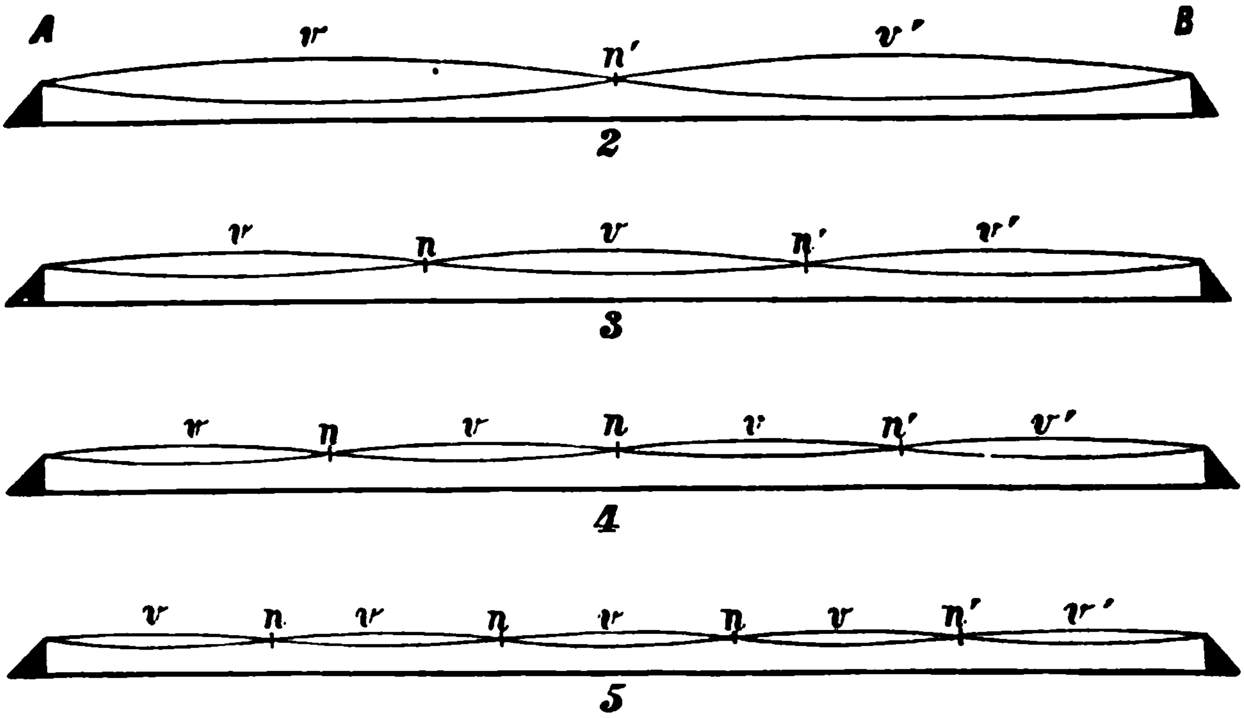


FIG. 280.—THE HARMONICS OF A VIBRATING STRING OR WIRE.

if formed of two wires, A n' and n' B. At n' the wire is at rest, or nearly so. This point is called a *node*. At v and v' is the greatest *excursion* or *bellying* of the string, and these places are called *the venters* (Latin, *venter*, the belly).

The two parts of the string vibrate with a seesaw motion about n', so that v and v' in all the diagrams of Fig. 280 are always moving in opposite directions. When the string vibrates with two venters, it gives out the higher octave of the note it gave when it had only one venter.

In the second, third, and fourth diagrams of Fig. 280, with 3, 4, and 5 venters respectively, the string makes 3, 4, and 5 times the number of vibrations it gave when it vibrated with only one venter. If the number of vibrations a second is 100 when the string vibrates with one venter, then it will make 200, 300, 400, and 500 vibrations when it has 2, 3, 4, and 5 venters.

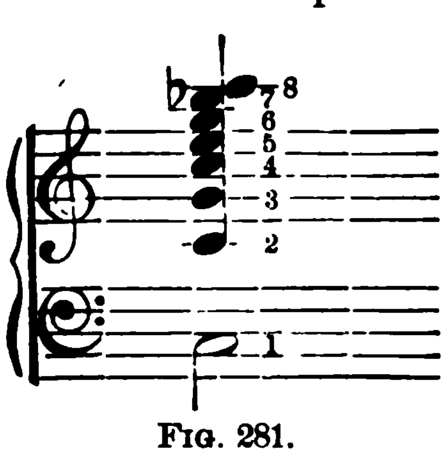


FIG. 281.

If the string is so stretched that it gives out the note C below the middle C of the piano (shown in the bass clef, Fig. 281) when it vibrates with one venter, it will give the notes numbered 2, 3, 4, 5, 6,

7, 8 (shown in the treble clef), when it vibrates with 2, 3, 4, 5, 6, 7, 8 venters. These notes are called the harmonics of the note in the bass clef, and are given by 2, 3, 4, 5, 6, 7, 8 times the number of vibrations given by the C in the bass. Under Analysis of Sounds, we shall see that, when a piano-string is struck by its hammer, all these harmonics except the seventh are present in its sound.

The nature of vibrations in strings may be effectively studied by means of the zithern, a cheap toy consisting of a sounding-board crossed by 24 wire strings (see No. 5, page 370). If a finger be placed on the center of one of the strings and the string be then vibrated, it will yield a note an octave higher than its fundamental note.

The Vibrations of Rods, Tuning-Forks, and Reeds.—A rod, clamped in a vise, is shown at *a*, *b*, *c*, *d*, *e*, in Fig. 282. If we pull the rod aside, it will vibrate till the energy of its oscillations has been given to the air and to the vise, and has been expended partly in heating the rod itself. These vibrations have the same kind of motion as that of a swinging pendulum; so have all bodies, such as strings, prongs of tuning-forks, plates, membranes, air in organ-pipes, etc., which give forth musical sounds.

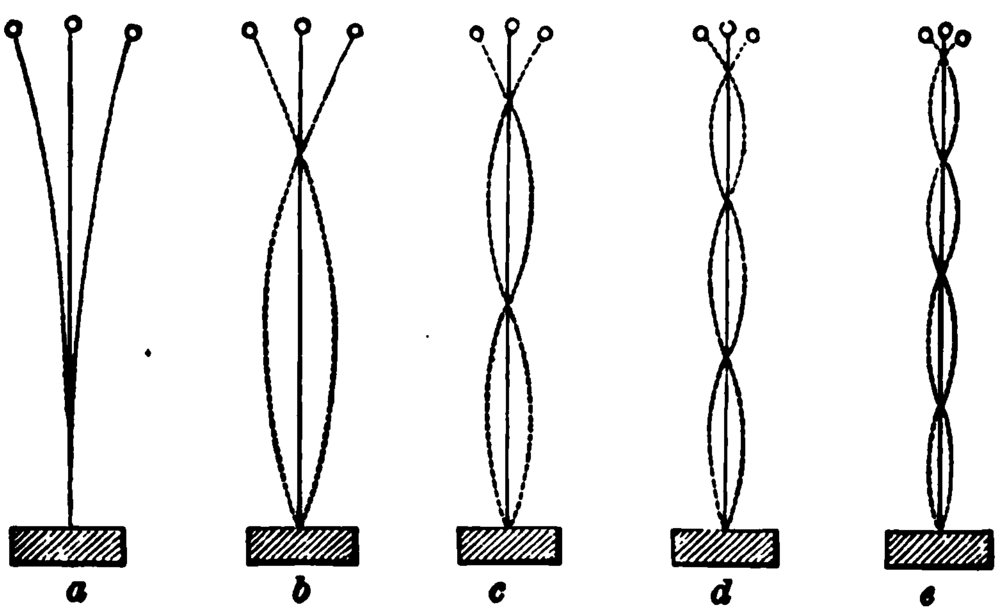


FIG. 282.—VIBRATING RODS.

If we place a soft body at the nodal points of *b*, *c*, *d*, *e*, and draw a bow across the rod near the center of a venter, the rod will, like a string, divide itself into segments of vibration with nodes, as shown in the figures, and the sounds given by the rod when it has these nodes will be far sharper than the sound given when the rod vibrated, as shown at *a*.

An interesting example of a vibrating rod is a tuning-fork, and you here have the analysis of its motions as determined by experiments. Let *a a* in Fig. 283 represent a steel bar resting on cords at points

shown by the short, perpendicular dotted lines. These dots show the position of the nodal lines of the bar when it is struck in the center.

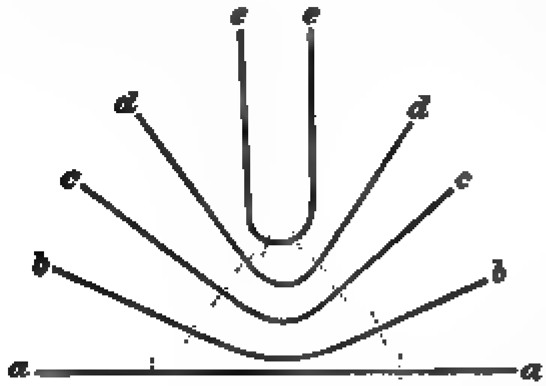


Fig. 283.—From the Vibrating Rod to the Tuning-Fork.

Now, suppose the bar bent from the straight line *a a* into the curve *b b*. The two nodal lines exist, but approach each other. We may continue to bend the rod, causing it to pass through the forms *c* and *d* to *e*, when we have the tuning-fork.

The nodes, during these successive bendings of the rod, have approached each other, as is shown by the dotted lines, till in the tuning-fork they are close together (*p* and *q*) and near where the prongs of the fork curve inward. The fork (Fig. 284) now vibrates like the unbent rod out of which it was formed, oscillatting to and fro about its nodal planes. The prongs approach each other, then recede. When they approach, the foot of the fork is pushed down. When they recede, the foot moves up, and thus the fork communicates its vibrations to any body on which it may be placed, for example, to a resonant-box of such interior dimensions as to be in tune with the fork.

In various musical instruments, thin plates or rods are used Thus, in the zylophone, vibrating wooden rods, and in the glass harmonica, strips of glass, are supported at their nodes on cords. These rods or glass plates are struck with a light wooden hammer, and give sounds of life and brilliancy. In the common music-box, free steel tongues, arranged in the form of a comb and made fast at one end, vibrate at the other when lifted by the pins of a revolving cylinder, yielding their individual notes. In the *vox-humana* and other reed-pipes of the organ, in the reed-organ, and in the clarionet, reeds or thin plates are set in vibration by blasts of air. The sounds given by these reeds are re-enforced and modified by their setting in vibration the air contained in pipes or cavities of various forms and sizes.

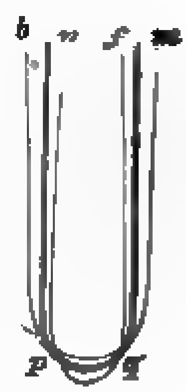


Fig. 284.—Vibrating Fork.

Vibrations of Plates.—When a circular plate of brass, glass, or other elastic substance, is fastened at its center to a support, and a violin-bow is drawn, perpendicularly to the surface of the plate, across a point on its edge, the plate vibrates and gives forth a sound. To discover how such a plate vibrates, Chladni spread fine sand over it; then, on causing it to vibrate, he saw the sand at first violently agitated, but in a few moments come to rest in narrow wind-rows running from the center of the plate, as shown in Fig. 285.

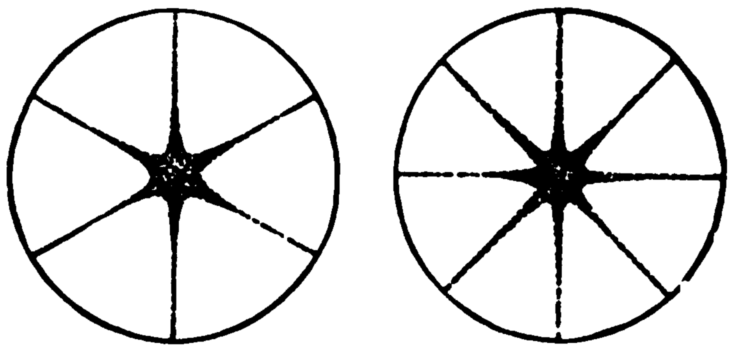


FIG. 285.—CHLADNI'S FIGURES.

These figures, formed by sand on vibrating plates, are hence called Chladni's figures; and the lines of rest, nodal lines. The plate always divides into an equal number of vibrating sectors. This is explained by the well-established fact that, in adjacent sectors, it always vibrates with opposite directions of motion; the line of sand separating any two sectors is thus a nodal line, where there is very slight motion, or absolutely none.

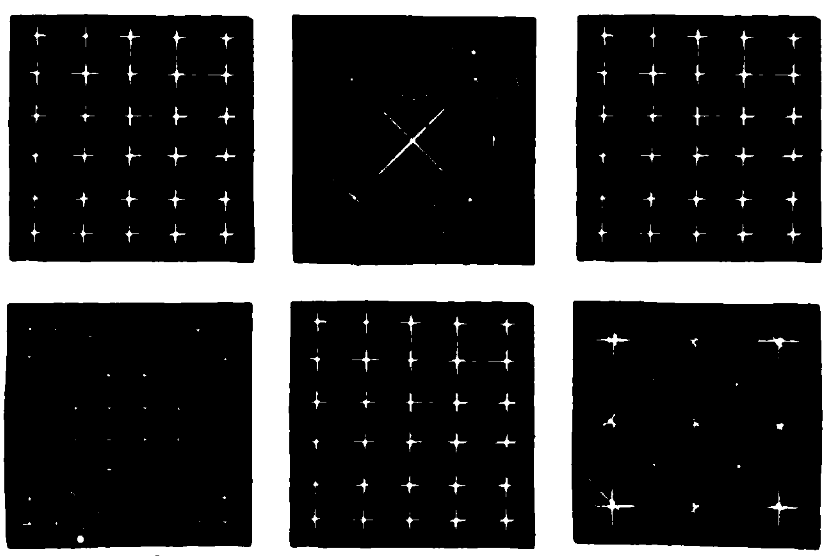


FIG. 286.—PATTERNS ON VIBRATING SQUARE PLATES.

Fig. 286 illustrates some of the patterns obtained by vibrating square plates. Press two fingers against the edge of the plate selected for the experiment, at points where nodal lines are to appear, and draw the bow of a violin across the plate, midway between the points held at rest by the fingers. A characteristic figure will be immediately formed.

Vibrations of Bells.—A bell may be considered as a plate formed into a spherical surface. Bells have nodal lines or planes of rest, and ventral surfaces where the vibrations are greatest, and opposed in direction on opposite sides of the nodal lines. Fig. 287 shows how a bell struck by the

clapper at *a*, *b*, *c*, or *d*, will have at these points the center of a venter, while the nodal points are half-way between these points, at *n*, *n*, *n*, *n*. The nodes and venters may be found by suspending to a string a small ball of ivory or of metal. When the ball touches the bell at *a*, *b*, *c*, or *d*, it is violently repelled, while at *n*, *n* *n*, *n*, it is very slightly agitated.

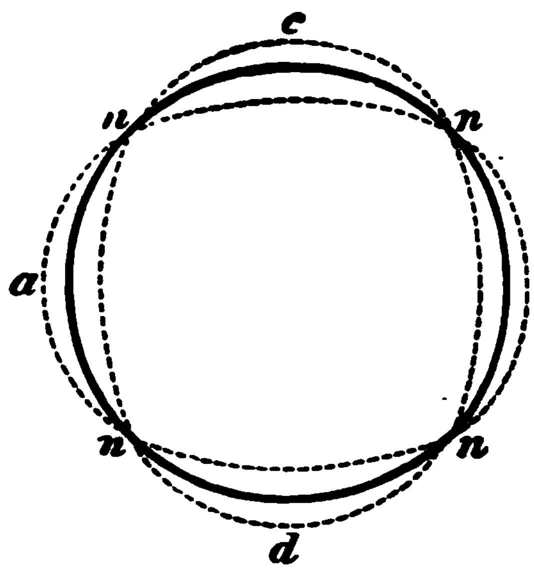


FIG. 287.—VIBRATING SEGMENTS AND NODES OF A BELL.

Vibrations of Columns of Air.—Fig. 288 represents a glass tube, T, with a cork in it which can be slid to various positions. By adjusting the cork we obtain various depths of air in the tube, from its open mouth *b* to the cork *c*. On vibrating a tuning-fork over the mouth of the tube, while the cork is gradually slid along the tube, we soon learn that, at a certain position of the cork, the sound of the fork is greatly increased in loudness; and that, when the cork is removed from this position, the sound rapidly diminishes in intensity. If the diameter of the tube be small compared to its length, we shall find that the re-enforcing of the sounding-fork reaches its maximum when the depth of the column of air measures one fourth of the wave-length of the sound given by the fork.

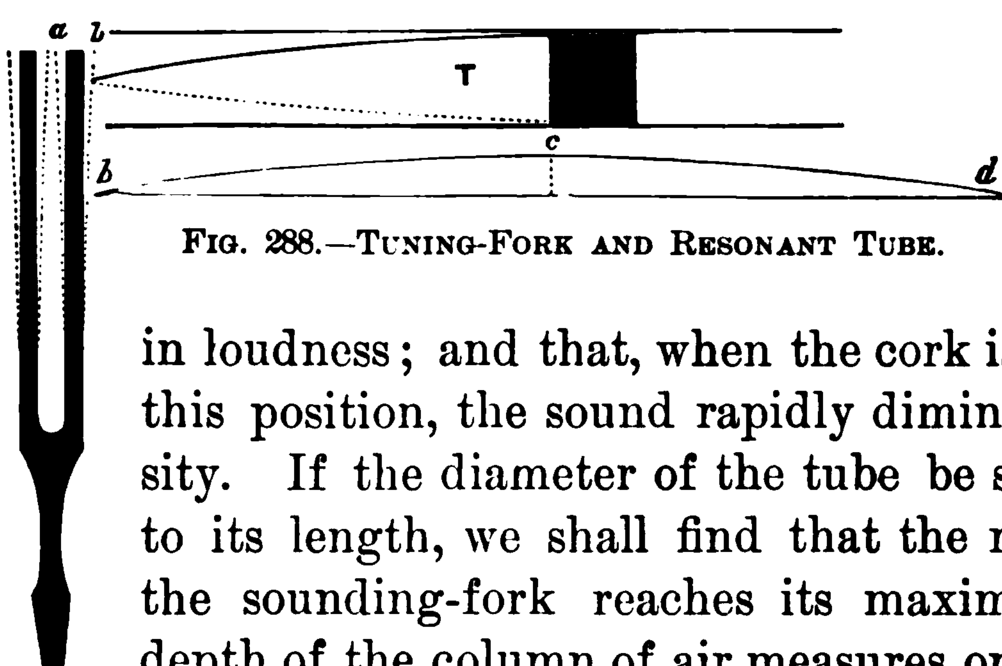


FIG. 288.—TUNING-FORK AND RESONANT TUBE.

The simple formula $l = \frac{v}{n}$, in which l = the length of the sound-wave, v = the velocity of sound at the temperature of the air in the tube, and n = the number of vibrations a second made by the fork, gives us the means of determining the length of $\frac{1}{4}$ of the sound-wave propagated by the fork. If, for example, the fork makes 256 vibrations

a second, and the temperature of the air is 65° Fahr., then $l = \frac{v}{n}$ or $l = \frac{1{,}123}{256} = 4{\cdot}38$ feet, or $52\frac{1}{2}$ inches. One fourth of $52\frac{1}{2}$ inches is $13\frac{1}{8}$ — the length of the column of air in the tube which resounds to 256 vibrations a second.

The explanation of the above fact is as follows: The prong of the fork and the air at the mouth of the tube must vibrate together; otherwise, there will be interference between these vibrations, and the air in the tube can not vibrate with the fork and re-enforce the sound the latter originates. We have previously learned that the fork, in going from *a* to *b* (Fig. 288), makes one half wave-length in the air before it. This may be represented by the curve *b c d*, above the line *b d*. Now the tube T must be as long as from *b* to *c*, or one quarter of a wave-length, so that, by the time the prong of the fork has gone from *a* to *b*, and is just beginning its back-swing from *b* to *a*, the half-wave *b c d* has just had time to go to the bottom of the tube T, to be reflected back, and to reach the prong *b* at the very moment of its back-swing. If it does this, then the end of this reflected wave (shown by the dotted curve on the tube T) moves backward with the back-swing of the prong *b*, and thus the air at the mouth of the tube and the prong of the fork swing together, and the sound given by the fork is strengthened.

It is evident that, if the fork makes double the number of vibrations per second over the mouth of the tube, the column of air in the tube will have to be shortened one half in order that it may resound; and, if the fork makes half the number of vibrations, the depth of air in the tube will have to be doubled to re-enforce the sound of the fork. In other words, the laws ruling these phenomena of resonant tubes are, that the lengths of resonant tubes are inversely as the number of vibrations to which they resound.

Organ-Pipes are simply resonant tubes. The air in such pipes is set in vibration by vibrating reeds, or by air driven through a mouth-piece like a whistle's, instead of by the fork as in our experiments. The relation between the lengths of organ-pipes and the numbers of vibrations they give is approximately the same as in the case of resonant tubes, viz., the numbers of vibrations a second given by organ-pipes of similar form are inversely as their lengths.

If in the equation $l = \frac{v}{n}$, we know two quantities, we can determine the third; thus, $v = l\,n$, and $n = \frac{v}{l}$. If we know the number of vibrations of the fork per second, or n, and, by the experiment cited above, obtain the length of the wave, or l, then we may compute the velocity of sound in air at 65° Fahr. by multiplying n by l. In the experiment given, n equaled 256, and l was 4·38, and $256 \times 4{\cdot}38 = 1{,}121$. This is one of the methods which has been used to obtain the velocity of sound in various gases.

QUESTIONS.—State the laws that govern the Vibrations of Strings. By what experiments have these laws been determined? Describe the Sonometer. Mention the variety of notes given by a stretched string. What will be the effect of halving its length? Of quartering its length? What is a node? A venter? Explain what is meant by the harmonics of a vibrating string. *They are "the notes corresponding to the division of the string into its aliquot parts."* What practical use may be made of the zithern in this connection?

Draw on the blackboard a series of figures showing how a rod may be made to divide itself into segments of vibration, like a string. When will the sound be higher pitched? What interesting analysis of the motions of the tuning-fork can you give? How may musical tones be obtained from vibrating rods, plates, and reeds? Describe the principle of the common music-box. What are Chladni's figures, and how are they produced? Illustrate, by means of a diagram, the nodal planes and ventral surfaces of a bell. How may the nodes and venters be detected?

What is meant by re-enforcing the sound of a tuning-fork? In the case of the fork and the resonant tube, when does this re-enforcement reach its maximum? What formula affords a means of determining the length of sound-wave propagated by the fork? Define a wave of sound, and wave-length. What are organ-pipes? What relation exists between their lengths and vibrations?

ELEMENTS OF SOUND.—MUSICAL SCALE.

Sounds are distinguished by Three Qualities—*pitch*, *intensity* or loudness, and *timbre* (tim'ber).

Pitch is that quality of a sound by which we distinguish its position in the musical scale. Thus, we speak of a sound being *higher* or *lower* than another. Pitch depends on the number of vibrations made by the sounding body in a certain fixed unit of time, the second.* The greater the num-

* In this country, and in England and Germany, a vibration is understood to be a movement to *and* fro of the vibrating body. In France, a vibration is a movement to *or* fro. Hence the vibrations given by French writers have to be halved to correspond with those we use.

ber of vibrations, the higher the pitch. Thus, if we have three sounds, and the numbers of their respective vibrations are to each other as 1 : 2 : 4, then the second is one octave above the first, and the third is an octave above the second and two octaves above the first.

The ordinary ear is sensitive to sounds produced by vibrations varying between 40 and from 12,000 to 20,000 a second. If vibrations fall on the ear fewer in number than 40 to the second, they do not blend as a musical sound, but give a sensation resembling the beats of two bass organ-pipes which are considerably out of tune. The limit of sensibility to sounds of high pitch varies in different persons. The results of some experiments made by the author in Washington in 1875, on the hearing of Chief-Justice Waite, Prof. Joseph Henry, and on his own ear, are as follows:—

Limit of audition of acute sounds by
Prof. Joseph Henry, 12,800 vibrations.
Alfred M. Mayer, 16,400 "
Chief-Justice Waite, 20,500 "

Fig. 289.—The Simple Siren: Rise of Pitch with Number of Vibrations.

As some persons are born color-blind, so there are others who are deaf to certain notes. Most men lose the power of appreciating very high notes with advancing age, and sudden shock or prolonged mental strain has been known seriously to impair the sensibility of the ear to sounds of different pitch. We have seen that there are many objects invisible to the unaided eye; so there may be sounds produced by insects (implying over 30,000 vibrations to the second) that are wholly inappreciable by the human ear.

That the Pitch rises with the Number of Vibrations, is proved by the simple apparatus shown in Fig. 289. A cardboard disk about 8½ inches in diameter revolves about its center on the rotator. The disk has four series of holes, each series equally spaced on its respective circle (see Fig. 290). On the first or inner circle are 24 holes, on the second 30, on the third 36, and on the fourth 48. These numbers are to each other as 24 : 30 : 36 : 48, or as 4 : 5 : 6 : 8.

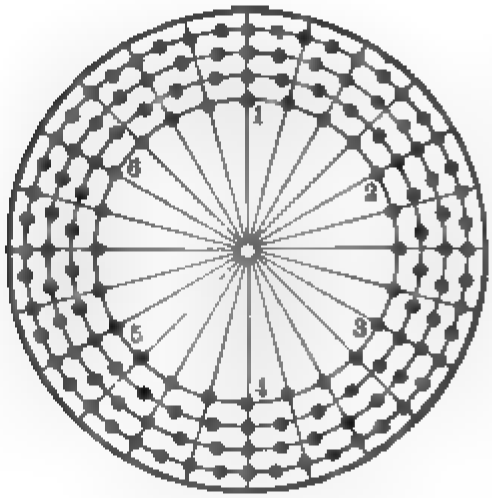


FIG. 290.—CARDBOARD DISK.

If we rotate the cardboard disk with a uniform motion and blow through a glass tube placed close to and opposite the inner series of holes, we shall produce a sound having the character of a musical note. This sound is caused by vibrations made by the puffs of air which pass through the holes as they successively come in front of the tube. If we pass the tube from the first to the second, third, and fourth ring of holes, the sound at each new position of the tube rises in pitch, and the ear distinguishes in the sequence of these sounds the major chord.

In other words, if we rotate the disk so rapidly that we obtain from the first series of holes the C of the treble, then from the second, third, and fourth series of holes we shall have the sounds of E, G′, and C′ of the octave above the treble C. These musical intervals are always given by sounds whose vibrations have the ratios of 4 : 5 : 6 : 8.

If we hold the tube stationary before any one of the series of holes, we shall find that the sound rises in pitch as we increase the rapidity of rotation, and falls as we slacken the speed of the disk.

The Siren (Fig. 291) is an instrument similar in action to the one just described, and much used to determine the pitch of sounds. It consists of a metal cylinder into whose base air is blown. The top of the cylinder is perforated

with a number of holes. Just over this top; and nearly touching it, rotates a metallic disk on a vertical axis. This disk is perforated with the same number of holes as are in the cylinder. The form of the holes is shown in section in the figure. They do not pass perpendicularly through the plates, but slope contrariwise, so that the air when forced through the holes in the top of the cylinder impinges on one side of the holes on the rotating disk, and thus blows it round in a definite direction. The disk, in making one revolution, opens and shuts the holes as many times as there are holes in the disk and cylinder, and hence the wind escapes from the cylinder in successive puffs, the frequency of which depends on the velocity of rotation. A sound is thus produced whose pitch rises with the velocity of the disk. The vertical axis of the disk has a screw cut on it which works on a notched wheel attached to a dial marking the number of rotations.

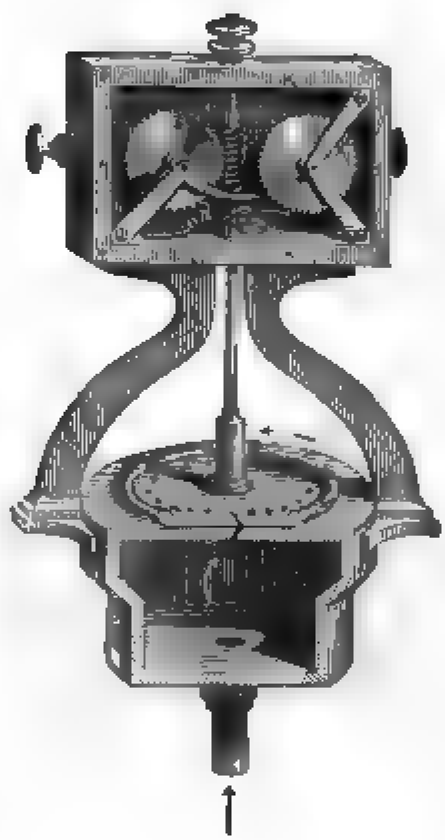


FIG. 291.—THE SIREN.

To determine the pitch of a sound with this instrument, we gradually increase the rotation of the disk until the sound given out approaches the pitch of the sounding body the number of whose vibrations we would determine. When the two sounds are quite near in pitch, the ear perceives distinct beats produced by their joined action on the air. The velocity is now cautiously increased by regulating the blast of air through the instrument until the beats just disappear. The disk is then allowed to run for a known number of seconds, during which it is connected with the counter. The number of rotations is thus recorded. If this number be multiplied by the number of holes in the disk, and the product divided by the number of seconds the disk was connected with the counter, the number of vibrations per second causing the sound in question will be determined.

The Intensity of a sound depends on the energy of the air vibrations which strike the ear, and therefore on the *amplitude* or extent of the vibrations of the sounding body itself. The loudness of two sounds of the same pitch varies as the square of the amplitude of the air vibrations. After a gong has been struck, the effect on the ear gradually diminishes, as the vibration is contracted in *extent*, during the return of the vibrating surface to rest.

The intensity of sound, like that of light, has been found to vary inversely as the square of the distance. Furthermore, it depends on the density of the medium in which the sound originates and is propagated. The denser the air the louder the sound, because the quantity of matter impinging on the drum-skin is greater. Hence, sounds produced on high mountains, where the air is rarefied, are correspondingly diminished in intensity. We have seen that in a vacuum there can be no sound ; but in the pneumatic cais'son employed in constructing bridge-piers in deep water, the air is unnaturally compressed, so that conversation in ordinary tones is painful to the ear.

Timbre is a quality of sound which affords a striking analogy to color in light. We may have a red and an orange light, both of the same intensity; but the eye distinguishes one from the other. So we may have sounds of the same intensity and pitch, one from a tuning-fork, the other from a violin, piano, clarionet, or the human voice. Yet the ear distinguishes these sounds, and we readily name the source of origin in each case. German authors have an expressive term for this quality of sound. What we call *timbre* they call *Klangfarbe*, which in English is literally *sound-color.*

The different timbres of sound are produced by mingling various simple sounds, just as any color may be formed by mingling various proportions of red, green, and violet.

A Simple Sound is one in which the ear can distinguish only one sound of one pitch. Such is the sound of a tuning-fork vibrating gently on its resonant-box. The

sound of a closed organ-pipe is also very nearly a simple sound. All simple sounds have the same timbre.

The sound of a piano-wire is an example of **a Composite Sound,** for it is composed of the mingling of several simple sounds. Thus, if we strike the treble or middle C of the piano, the educated ear can readily detect other and higher sounds mingled with that of this C. The latter sound is, however, the lowest in pitch and the strongest of the component sounds; but it is always accompanied by these higher sounds whose vibrations bear to those of C the ratios of 1 : 2 : 3 : 4 : 5 : 6 : 7 : 8, etc. These sounds are called *the harmonics*, or overtones, of C (see page 391).

If we designate the treble C by C_2, then the harmonics mingled with C_2 are as follows: C_3, G_3, C_4, E_4, G_4, $B\flat_4$, C_5, etc. The seventh harmonic, or $B\flat_4$, is wanting in the series, because the hammers of the piano strike the strings at points about one seventh of their length; and therefore this harmonic can not sound, for the blow of the hammer makes a *venter* at the point it strikes. For the seventh to appear there would have to be *a node* at this point. The seventh is thus purposely obliterated from the compound sound, for it is not in harmony with the other harmonics.

Analysis of the Sound of a Piano-String.—That these harmonics exist in the sound of the treble C_2 of the piano, is easily proved by the following interesting experiment: Depress slowly and firmly the key of C_3 on the piano. The hammer will rise, press against the wire, and fall from it; but the damper of this string will remain raised. Now, strike strongly the key of C_2, and after holding it for an instant stop its sound. We shall hear the sound of C_3 very distinctly, showing that it had been set into vibration by the vibration of C_2, and that C_3 must therefore exist as one of the component sounds of C_2. In like manner one can show that G_3, C_4, E_4, G_4, G_5, etc., are components of the compound sound of the wire of C_2.

Analysis of Complex Sounds.—There are many ways of detecting the number and the pitches of the sounds en-

tering into the formation of any complex sound. The sounds used in music are all complex, for a simple sound is without expression, lacks feeling or "brilliancy." We have already explained one method of analysis in which we have utilized the principle of co-vibration (see page 373). There are others which employ this same principle.

Suppose we wish to analyze the very complex sounds given by reed organ-pipes. Let us arrange around the mouth of the pipe tuning-forks mounted on their resonant-boxes. The lowest sound rendered by the pipe, or that of the note by which the pipe is denoted in the musical scale, is given by the fork lowest in pitch in the series of forks. On sounding the pipe, this fork will enter into vibration; and on stopping the sound of the pipe, the fork will sing out clearly the pipe's lowest or fundamental tone. But if we also have other forks whose vibrations per second bear to those given by the first fork the ratios of 2 : 3 : 4 : 5 : 6 : 7 : 8, etc., they will also sing out their respective notes; and when we stop the sound of the pipe, the united sounds or chorus of the forks will very well reproduce the peculiar timbre of the reed organ-pipe.

We thus in one experiment not only analyze the sound, but reproduce it by the chorus of its components.

Resonators of Helmholtz.—The most ready way of analyzing a complex sound is that suggested by Helmholtz. He employed a series of hollow brass or glass spheres, each having a circular opening *a* to admit the vibrations of the outer air to the air in the interior of the sphere. Opposite this opening is a nipple *b*, which fits in the ear, and thus conveys the vibrations to the auditory nerves.

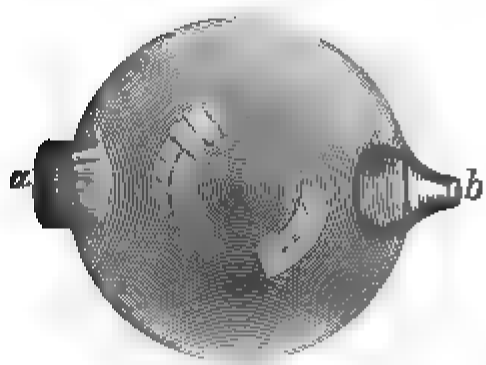


FIG. 292. HELMHOLTZ RESONATOR.

Each resonator is made of such dimensions that it is accurately in tune with a known simple sound, and the note of this sound is marked on the resonator. When this note is sounded in the air, the air in the resonator co-vibrates to it, and the sound of the note is heard with great distinct-

ness, to the exclusion of the other simple sounds that may be in any complex sound.

By applying one resonator after another to the ear, we analyze a sound into its components. It is thus found that the analysis of the sound of the piano-wire is the same that was reached by our experiment; that the sounds of a clarionet are formed only of the odd harmonics, or of simple sounds in the ratios of 1 : 3 : 5 : 7; and that the sounds of a flute are substantially those of a note and its octave.

The Musical Scale is formed of sounds differing in pitch by definite ratios of vibrations. The experiments with the simple siren (Fig. 289) showed that, when the ratios of the frequencies of the vibrations of four notes were as 4 : 5 : 6 : 8, we obtained a succession of sounds—so that, if the sound beginning the ratio, or 4, was that of the note C, then the other sounds were as follows: E, G, and c, of the octave above C. But this ratio of 4 : 5 : 6 serves to form the whole of the *natural scale of music*, thus: We decide on the number of vibrations a second which shall denote the treble C—264, for instance. Then—

(1) C : E : G : : 4 : 5 : 6 or as 264 : 330 : 396
(2) G : B : d : : 4 : 5 : 6 or as 396 : 495 : 594
(3) c : A : F : : 6 : 5 : 4 or as 528 : 440 : 352

By arranging these results in the order of the notes, we have the number of vibrations corresponding to the notes contained in the octave of the treble, viz.:

Notes,	C	D	E	F	G	A	B	c*
Vibrations,	264	297	330	352	396	440	495	528

The numbers above being divisible by 11, we may reduce the ratios of the vibrations to their simplest expression:

C		D		E		F		G		A		B		c
24	:	27	:	30	:	32	:	36	:	40	:	45	:	48

If we perforate the disk of the siren (Fig. 291) with holes arranged in 8 circles—the inner circle having 24 holes, and the succeeding circles 27, 30, 32, 36, 40, 45, and 48—then, on rotating the disk so that we obtain 264 vibrations a second by blowing through the circle of holes

* The small letter indicates the octave above that designated by the corresponding capital.

nearest its center, we shall obtain all the notes of the octave by blowing successively through the circles of holes, passing from the inner to the outer circle.

This natural scale is the only one which gives perfect harmony of chords. It is the scale which good singers use, and which the accomplished violinist produces from his instrument. But the extensive use of musical instruments with fixed tones, like the piano, melodeon, organ, and many wind-instruments, has given rise to a scale called *the equal-temperament scale.* In this there are twelve notes, and the octave is divided into *twelve equal intervals.* Each of these intervals is called *a semitone*, and two intervals form *a tone.*

If we take 264 as the number of vibrations of the C of the treble, then the vibration numbers per second of the 12 notes of the octave will be as follows:

C	C♯	D	D♯	E	F	F♯	G	G♯	A	A♯	B
264	280−	296+	314−	333−	352+	373+	395+	419+	444−	470+	498+
C		D	E♭	E	F		G	A♭	A	B♭	B
264		297	317−	330	352		396	422+	440	469+	496

The ratios above are given to the nearest integer. Where the note is slightly sharper, + is placed after it; where slightly flatter, — follows it. For comparison, the ratios of vibration-numbers of the perfect or natural scale are written under those of the equal-temperament scale.

The intervals of the equal temperament scale are so near to perfection that, when a succession of notes is sounded in a melody on the piano or organ, only the cultivated ear of a musician can detect the departure from accurate tuning in these instruments; but, when accomplished singers are accompanied either by piano or organ, the want of harmony between the voice and these instruments is apparent. This departure from accuracy is at once brought out when chords are sounded on the piano or organ.

The best violinists play *the natural scale*, as was shown by Helmholtz. He accurately tuned a harmonium, or reed-organ, to the natural scale, and Joachim (*yo'a-kim*), the eminent violinist, having brought his violin to the pitch corresponding to that of the harmonium, accompanied the latter instrument. It was found that the intervals played by Joachim were those of the natural scale.

QUESTIONS.—Name the three qualities that distinguish sounds. Define Pitch. On what does it depend? Between what limits of vibration is the ear sensitive to sound? Explain the sensation produced by vibrations fewer in number than 40 to the second. Give some idea of the limit of audition of acute sounds. State the effect of age on the power of appreciating high notes; the general effect of shock and mental strain. Prove that the pitch rises with the number of vibrations, drawing a diagram of a simple Siren to illustrate your arguments. Describe the method of determining the pitch of a sound with the siren.

On what does the Intensity of a sound depend? Can the loudness of sounds of the same pitch vary? How? What relation exists between intensity and distance? Between intensity and density of medium? What can you say of the intensity of sounds on high mountains? Explain Timbre, and the analogy to color. What is a simple sound? A composite sound? Explain the harmonics. Analyze the sound of a piano-string. Do the harmonics exist in the sound of the treble C_2? How may the number and pitches of the sounds forming any complex sound be determined? Describe the Resonators of Helmholtz.

Of what is the Musical Scale formed? What ratio forms the natural scale of music? Reduce the ratios of the vibrations to their simplest expression. How can we obtain all the notes of the octave with the simple siren? Explain the equal-temperament scale.

THE VOCAL ORGANS AND THE HUMAN VOICE.

How we Speak and Sing.—The little musical instrument with which we speak and sing is formed of two flexible membranes stretched side by side across a short tubular box placed on the top of the windpipe. This box, the *lar'ynx*, is made of plates of cartilage, movable on one another, and bound together with muscles and membranes.

The top of the windpipe is formed of a large ring of cartilage, called the *cricoid* (wing-shaped) *cartilage.* Jointed to this is a broad plate, called the *thyroid* (shield-shaped) *cartilage*, which has the form of the letter V. The angle of the V points toward the front of the throat, and is familiarly known as the "Adam's apple." On the back of the upper edge of the cricoid ring are jointed two small, pointed cartilages, known as the *aryt'enoid* (funnel-shaped) *cartilages.* Stretching from them to the inner surface of the thyroid are two yellowish-white elastic membranes, the so-called *vocal cords.*

When the point of the thyroid is not pulled down, these cords are loose, and the breath from the windpipe passes freely between them, and does not make them vibrate (see B, Fig. 293). But, when the peak of the thyroid is pulled down by its muscles, the vocal cords are stretched. At the same time the arytenoid cartilages move nearer

together, and the thin, sharply-cut edges of the cords themselves are brought parallel and quite close to each other, as is shown in A.

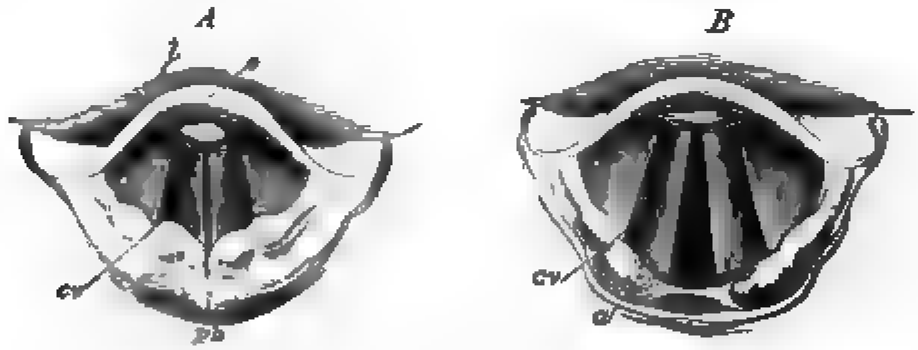


FIG. 293. HUMAN LARYNX AND VOCAL CORDS.

A and *B*, views of the human larynx from above as actually seen by the aid of the instrument called the laryngoscope; *A*, in the condition when voice is being produced; *B*, at rest, when no voice is produced; *e*, epiglottis (foreshortened); *cv*, the vocal cords; *a*, elevation caused by the arytenoid cartilages; *l*, root of the tongue.

If air from the lungs is now forced through the narrow slit between the cords (called the *glottis*) they vibrate like the tongue of a reed-pipe, and produce the sounds of the voice. The almost infinite variety of sounds that one can evoke from this instrument is the result of various degrees of stretching (tension) of the vocal cords, combined with the movements of the mouth, lips, and tongue.

The shorter and more tense the cords, the higher will be the pitch. The vocal cords being shorter in women and boys than in men, their

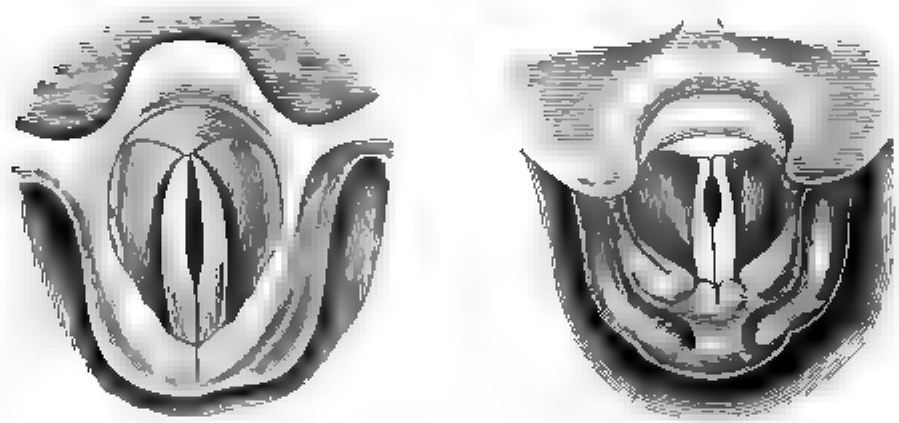


FIG. 294.—APPEARANCE OF THE VOCAL CORDS IN THE PRODUCTION OF THE FALSETTO VOICE.

voices are sharper, or higher-pitched, than those of the latter. When a boy reaches the age of fourteen or fifteen, his larynx develops rapidly, the cords lengthen, and his voice "breaks," falling usually an octave

in pitch. In exceptional cases, the development of the larynx is checked, so that the adult man is able to sing soprano parts. Some have the power of shortening at will the vibrating parts of the cords, and so producing falsetto notes of different pitch. In such cases, the cords may be brought closer together posteriorly, or both in their posterior and anterior portions, as shown in Fig. 294.

Disorders of the Voice.—The production of the simplest tone implies freedom of the vocal cords to approach each other; and complicated vocal effects involve the action of nearly 100 muscles in producing and driving the current of air, regulating the tension of the cords, and changing the size and form of the oral cavity. Hence the power and quality of the voice are extremely subject to changes. All depressing diseases weaken the voice; any interference with the perfect or regular approximation of the cords, as in the case of a cold or straining of the voice, causes hoarseness or huskiness; and certain forms of paralysis and painful affections of the throat, in which the cords can not meet, are marked by *aphonia*, or complete loss of musical tone. The human voice is also peculiarly susceptible to emotional influences; hence the hoarseness or tremulous utterance of passion, the speechlessness of fear, etc.

Speech is voice modified and modulated by the movements of the lips, the tongue, and the parts of the cavity of the mouth. The oral cavity is made larger or smaller, longer or shorter, and thus, resounding to some lower or higher harmonics of the voice, it makes the others feebly heard.

All the vowel-sounds are formed by a steady voice, modified by the resonance of the different sizes and shapes given to the cavity of the mouth. The consonants are made by obstructions placed at the beginning or end of the oral sounds, by the movements of the tongue and lips.

The lower animals have voice, but are without the power of significant articulate speech. The utterances of the parrot are mechanical, not intelligent.

Koenig's Manometric Flames.—Many interesting and instructive experiments with the human voice may be made by means of a simple apparatus invented by Koenig, of Paris. Fig. 295 shows it in a simple form. An upright

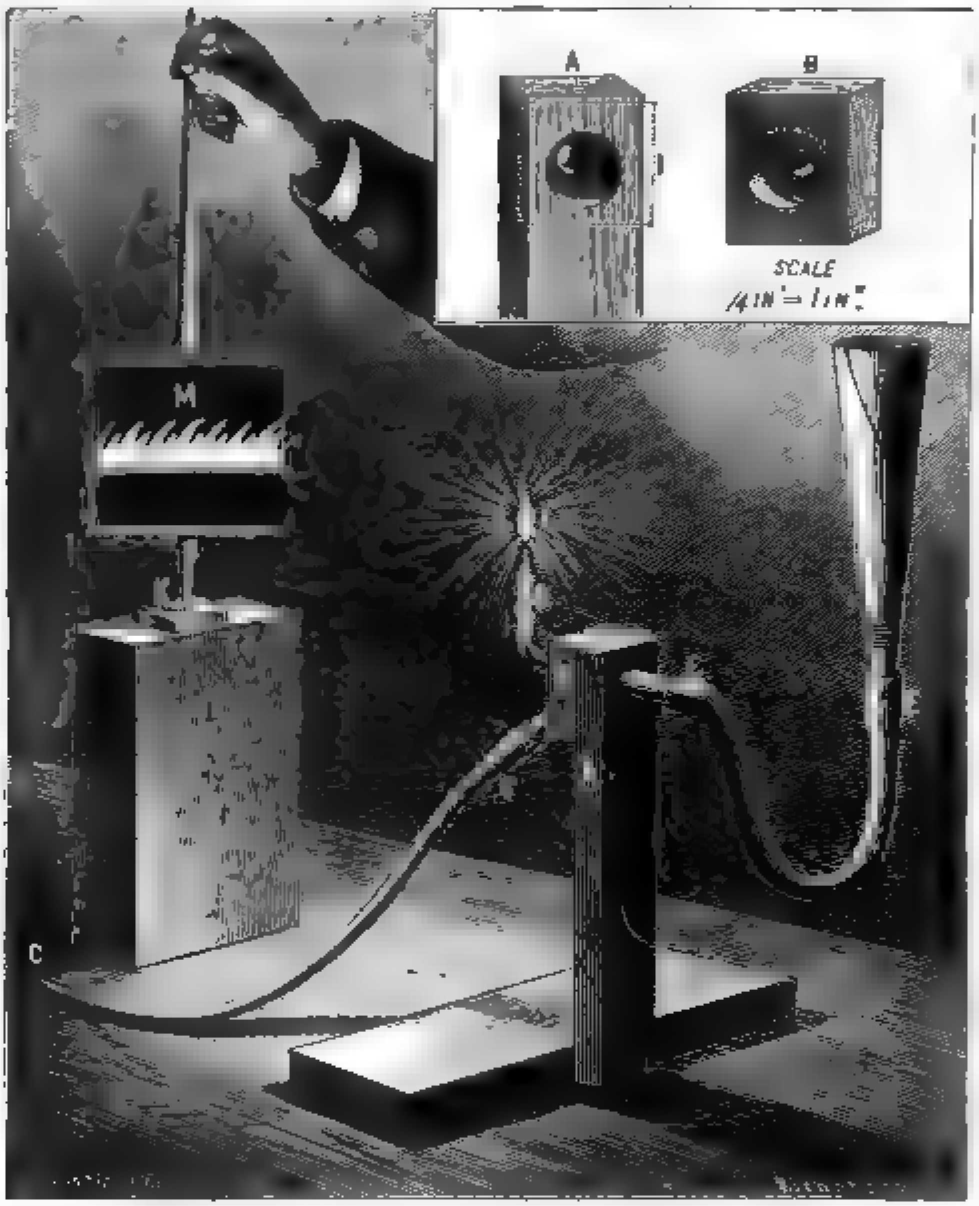


FIG 295.—ANALYSIS OF SOUNDS WITH MANOMETRIC FLAMES.

piece of wood, A, noted also in the corner of the figure, has a hole bored in it by a center-bit. This hole does not pass entirely through the piece of wood, but another and smaller hole is bored in the center of the one just formed. Similar holes are bored in the block B, which has also an-

other hole bored obliquely into the cavity formed by the center-bit. A piece of very thin paper, gold-beater's skin, or India-rubber, is placed over the large hole of the block A so as to cover it, and is cemented to the block by glue or mucilage. The block B is then placed on A, as shown, and these two pieces of wood are glued together.

We have now a box separated into two compartments by the sheet of rubber. Into one of these compartments gas is led by a rubber tube, as shown. This gas issues from the box by the tube D, whose upper end is drawn out into a burner. The gas is lighted at F, and then lowered till it burns with a small bright flame.

Into the other compartment of the box enters a large glass tube, E, to which is attached a rubber tube having at its other end a cone made of cardboard. A flat piece of wood is cut out, as shown at M, and by means of rubber bands two pieces of mirror are fastened to the faces of the board. The upright rod of the mirror is rotated in a conical cavity formed on the block K, which rests on the brick L.

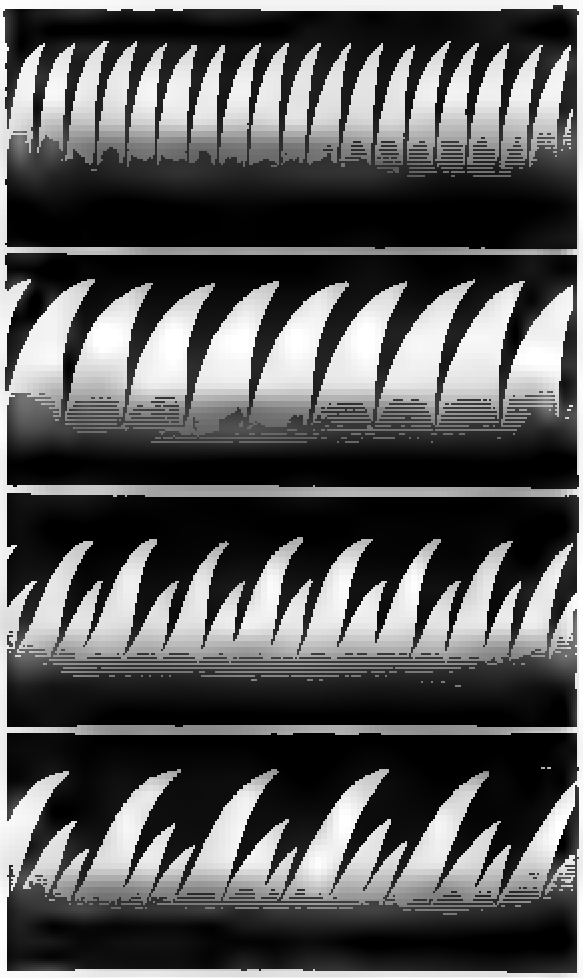
When you sing into the cone while the mirror is twirled between the fingers, the flame viewed in the mirror presents the appearance of a band of light with its upper edge cut into teeth like those of a saw. This shows that the flame is vibrated by the action of the voice on the membrane, which divides the box into halves. On one side of the membrane is the flowing gas; on the other, the air in a state of vibration.

When the condensed half of a sound-wave falls on this membrane, the latter is forced into the compartment in which is the gas, and the gas is driven out of the tube D in a short puff, causing the flame suddenly to rise in height. At the next instant the membrane goes in the opposite direction under the action of the rarefied half-wave, and the flame suddenly falls. These motions succeed each other several hundred times in a second.

When the mirror is revolved and no sound-vibrations enter the cone, the reflection from the mirror draws the light of the flame into a brilliant band or ribbon; but on singing into the cone, you will see the flame vibrate, and the upper edge of the band become serrated. Each tooth shows a vibration of the membrane, which thus faithfully gives an account of its motions on the flame reflected from the mirror. As you change the note of your voice, the appearance of the flame will change. If the mirror is revolved regularly, then, as the pitch of the voice rises, the number of teeth increases in the band of light,

Experiments.—The following experiments give much information about the sounds of the voice:

Sing into the cone the sound of *oo* in *pool*. After a few trials, you will obtain a simple sound, and the flame will appear as in Fig. 296 *A*.



A

B

C

D

Fig. 296.

While twirling the mirror with the same velocity it had during the preceding experiment, lower your voice to the octave below the *oo* just sung, and the flame will appear as in Fig. 296 *B*, with one half the number of serrations, because the lower octave of a note is given by one half the number of vibrations.

Sing the song *o* on the note,

and you get Fig. 296 *C*. This is evidently not the figure that a simple sound gives. It is formed of alternating large and small teeth. The larger teeth are made by every alternate vibration of the octave of the higher sound coinciding with a vibration of the octave below Such is the character of the generality of sounds given by a flute.

Fig. 296 *D* appears on the mirror when we sing the English vowel *a* on the note *f* of the octave above the treble. This sound is made up of two simple vibrations combined. One of these alone would make the long tongues of flame; but with this simple vibration exists another of three times its frequency that is, the latter is the third harmonic of the lower sound.

Questions.—Describe in detail the human larynx with its appendages, and the action of the vocal cords in producing the Voice. What causes a high-pitched voice? A low-pitched voice? Explain the difference between the voice of a woman and that of a man; the production of falsetto tones. Illustrate the sensibility of the voice to disease, strain, and emotional influences. What is Speech? Explain the production of vowels and consonants.

Describe Koenig's manometric flames, and state what is to be learned from them. Enumerate certain experiments which give much information in regard to the sounds of the voice.

THE TALKING-MACHINES.—HARMONY AND DISCORD.

The Vocal Cords and the Larynx, with the cavities of the mouth and nose, form, as has been shown, an instrument similar to a reed-organ pipe. A vox-humana pipe can be made to articulate some simple words like *papa'* and *mamma'*. These experiments are made by forming a cavity between the two hands, and then opening and shutting this cavity at the proper times, while the open mouth of the pipe is between the hands. Reed-pipes, with a little practice, can also be made to say "Amen," "Go away," and several other simple combinations.

Faber's Talking-Machine.—The experiments with the reed-organ pipe show the principles followed by Faber, of Vienna, in the construction of his celebrated talking-machine. A vibrating ivory reed, of variable pitch, forms the vocal cords. There is a mouth-cavity, whose shape and size can be rapidly changed by depressing the keys on a key-board. Rubber tongue and lips make the consonants. A little windmill turning in the throat rolls the *r*, and a tube is attached to the nose of the machine when it is desired to produce the nasal sounds of French.

Edison's Talking Phonograph.—From this description it is evident that Faber worked at the source of articulate sound, and built up an artificial organ of speech, whose parts as nearly as possible perform the same functions as corresponding organs in our vocal apparatus. Faber attacked the problem on its anatomical side. Edison, however, considering the vibrations as already produced, it matters not how, makes them impress themselves on a sheet of metallic foil or on a hard wax composition, and then reproduces from these impressions the sonorous vibrations which caused them.

Figs. 297 and 298 will render intelligible the construction of Edison's invention. A cylinder, C, turns on an axle which passes through the two standards A and B. On one end of this axle is the crank D; on the other, the heavy fly-wheel E. The portion of the axle to the

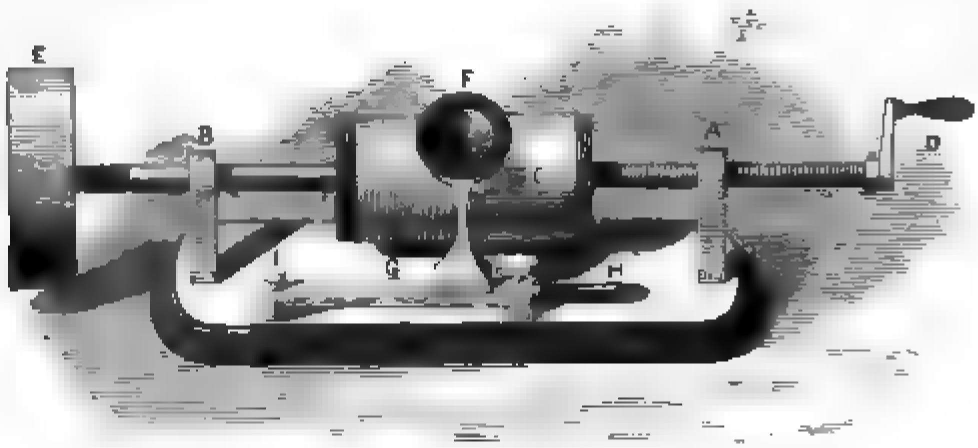


FIG. 297.—EDISON'S TALKING PHONOGRAPH.

right of the cylinder has a screw-thread cut on it, which, working on a nut in A, causes the cylinder to move laterally when the crank is turned. On the surface of the cylinder is scored a screw-thread similar to that on its axle. F (shown in detail in Fig. 298) holds a plate of iron about $\frac{1}{100}$ of an inch thick. This plate can be moved toward and from the cylinder by pushing on or pulling out the lever H G, which turns in a horizontal plane about the pin I.

The under surface of this thin iron plate (A, Fig. 298) presses against short pieces of rubber tubing, which lie between the plate and a spring attached to E. The end of this spring carries a rounded steel point, P, which, when brought up to the cylinder by the motion of the handle, H, enters slightly into the grooves scored on the cylinder, C. The distance of the point P from the cylinder is regulated by a set-screw, S, against which abuts the lever H G. Over the iron plate A is a disk of vulcanite, B B, with a hole in its center. The under side of this disk nearly touches the plate A. Its upper surface is cut into a shallow, funnel-shaped cavity, leading to the opening in its center.

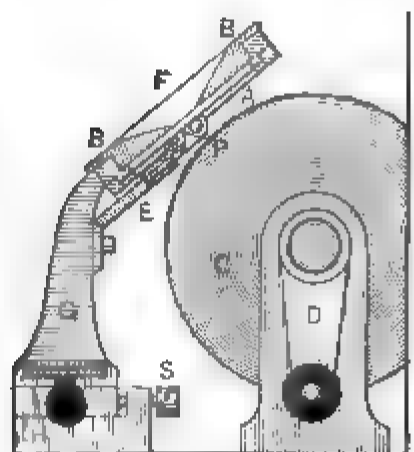


FIG 298. PRINCIPLE OF PHONOGRAPH.

To operate this machine, we first neatly coat the cylinder with a

sheet of foil, so that if we turn the cylinder it will make a depressed line or furrow where the foil covers it. The mouth is now placed close to the opening in the vulcanite disk, B B, and the metal plate is talked to while the cylinder is revolved with a uniform motion. The thin iron plate vibrates to the voice and the point P indents the foil, impressing on it the varying numbers, amplitudes, etc., of the vibrations. If the vibrations given to the plate A are those of simple sounds, then they are of a uniform regular character, and the point P indents the foil with regular undulating depressions. If the vibrations are those of complex and irregular sounds (like the sounds of the voice in speaking), then the depressions made on the foil are similarly complex and irregular. Thus the yielding and inelastic foil receives and *retains* the mechanical impressions of these vibrations.

A permanent impression having been thus made, we now obtain from these impressions the aërial vibrations which made them in the following manner: The plate A with its point P is moved away from the cylinder by pulling toward the experimenter the lever H G. Then the motion of the cylinder is reversed till there is brought opposite to the point P the beginning of the impressions it made on the foil. The point attached to the plate A is now brought up to the cylinder, and a large cone of paper or of tin is placed against B B to re-enforce the sound. The crank is then steadily turned. The elevations and depressions made by the point P now pass under this point, and in doing so cause it and the iron plate to make over again the precise vibrations which animated them under the action of the voice. The consequence of this is, that the iron plate gives out the vibrations which previously fell upon it, and thus repeats what was said to it in the very tones of the speaker.

Persons traveling in distant lands may now, after "speaking into" their phonographs, send the cylinders of wax composition by mail to their friends, who have simply to revolve these cylinders in similar instruments, and listen to the messages they utter. The phonograph is also used by physicians to record the sounds made in coughing. Peculiar coughs characterize different diseases and different stages of the same malady, and these may now be preserved for comparison and leisurely study.

The Improved Phonograph.—Edison has recently greatly improved his phonograph, and has given us a ma-

chine which reproduces speech and musical tones with all their delicate shades of expression and modulation. He has in this later machine replaced the metallic foil by a cylinder of a hard wax composition, which can be placed on and taken off the machine. This cylinder is turned by an electric motor, regulated by a governor. For the iron plate which received and reproduced the vibrations, he has substituted one of thin glass; and instead of the point which indented the tin-foil, he now uses a delicate chisel which cuts out the wax on the cylinder, and thus engraves in the wax the most delicate variations of vibratory motion of the thin glass plate.

Harmony and Discord.—If flashes of light succeeding one another a few times in a second enter the eye, a painful sensation is caused; but, if the number of flashes a second is increased till they exceed 10 or 20, a steady light is perceived and the disagreeable sensation vanishes. The reason of this is, that the impression of the flash of light remains as light on the eye about $\frac{1}{10}$ of a second, and, if another flash follows before the impression of the former has disappeared, the two sensations blend and we have a continuous sensation. On this fact Helmholtz constructed his theory of harmony and discord, by showing that the same effect was produced by what we may call flashes or *beats* of sound (see page 386). He did not, it is true, determine experimentally the number of beats in a second required by various sounds to blend into a continuous sensation. This was first done by Prof. Mayer, who found out the facts by experiments with disks perforated with various sizes and numbers of holes, which admitted and shut off the sound, and thus produced flashes of sound on the ear.

Thus it was found that the duration of the sensation of a sound depends on the pitch of the sound, and that the higher the pitch the less the duration of the sonorous sen-

sation. The following table gives the results of these experiments :—

N	V	B	D
C	64	16	$\frac{1}{16}$ = ·0625 sec.
c	128	26	$\frac{1}{26}$ = ·0384 "
c′	256	47	$\frac{1}{47}$ = ·0212 "
g′	384	60	$\frac{1}{60}$ = ·0166 "
c″	512	78	$\frac{1}{78}$ = ·0128 "
e″	640	90	$\frac{1}{90}$ = ·0111 "
g″	768	109	$\frac{1}{109}$ = ·0091 "
c‴	1024	135	$\frac{1}{135}$ = ·0074 "

Column N gives the names of the notes corresponding to the vibrations a second in column V. The c′ in this series is that used by physicists generally, and gives 256 vibrations. In column B is presented the smallest number of beats a second which the corresponding sound must make with another in order that the two may be in harmony, or, as it is generally stated, may make with the other the *nearest consonant interval.* If 47 beats a second of c′, for example, blend, then the sensation of each of these beats remains on the ear $\frac{1}{47}$ of a second. In column D are given these durations in fractions of a second. As these fractions are the lengths of time that the sensation lingers in the ear after the vibrations of the air near the drum-skin have ceased, they are very properly called *the durations of the residual sonorous sensations.*

Observe, in the table, that this duration becomes shorter as the pitch of the sound rises. Thus, while the residual sensation of C is $\frac{1}{16}$ of a second, that of c‴ is only $\frac{1}{135}$.

The discord produced by two sounds, Helmholtz explains by the fact that the sounds produce *beats,* which do not blend because they are too few in a second; but, if the two sounds be gradually made to differ more and more in pitch, the beats increase in number and at last blend into a smooth, *continuous sensation.* He defines discord as *a discontinuous sensation,* harmony as *a continuous sensation.*

The beats given by two sounds in a second are equal to the difference of their numbers of vibrations in a second. Thus, if we had one sound given by 256 vibrations a second and the other by 320, their difference is 54. Our table shows that, for 256 vibrations, only 47 are required to blend into a continuous sensation, so these two sounds are in harmony. This is well known, for they are the sounds of c and of E, and form the major third.

Suppose we had two sounds falling at the same time on the ear, one of 256 the other of 303 vibrations a second. The difference of these numbers is 47. Referring to the table, we see that the sound of 256 vibrations remains on the ear $\frac{1}{47}$ of a second; therefore these sounds just form a harmonious combination—the minor third of the treble.

Assume that the *c* of 256 vibrations and the *d* of 238 vibrations a second are heard simultaneously; the difference here is 22, but 47 vibrations are required to produce a continuous sensation. Hence these two sounds form a discord. They are separated only by a tone on the piano. Thus, through the whole musical scale we can, from the table given, determine beforehand what notes, when sounded together, will make harmony, and what notes will give discord.

QUESTIONS.—Describe Faber's talking-machine; Edison's Phonograph, illustrating the principle by diagram. What use has been made of the phonograph? On what analogy did Helmholtz construct his theory of Harmony and Discord? Explain discord. Give Helmholtz's definition of harmony and discord. How may we determine what notes, when sounded together, will make harmony?

MISCELLANEOUS QUESTIONS AND PROBLEMS.

What analogies have you discovered between Sound and Heat and Light?

The steth'oscope, employed by physicians in making physical examinations, consists of two tubes, terminating at one end in a flange which is applied to the chest, and with ivory tips at the opposite extremities of the tubes for insertion in the ears. Explain the principle by which healthy and abnormal sounds in the heart and lungs are made known in an exaggerated form to the examiner.

If the temperature of the air is 62°, what is the wave-length of a sound whose vibrations are 280 to the second?

What is the cause of the difference between a bass and a soprano voice?

What kind of a medium is required for the transmission of sound-waves? *An elastic medium, which may be solid, liquid, or gaseous.*

If a sound travels a half-mile in $2\frac{1}{4}$ seconds, what is the temperature of the air?

There is a well in Carisbrooke Castle, Isle of Wight, 240 feet deep. How much time elapses after a pebble is dropped into the well before the sound of the splash reaches the ear?

Does confusion arise from our hearing sounds with two ears? *It is believed that two ears possibly correct the errors of each other; they certainly help us to determine the place whence sounds proceed.*

Why was it possible for boys, in the absence of actresses, to personate successfully on the Elizabethan stage the heroines of Shakespeare's plays?

If I fire a gun among the mountains and hear the first echo in two seconds, about how far away is the nearest reflecting surface?

Why do shells of a certain shape murmur when held to the ear? *Because they form resonators which re-enforce sounds in the air. How?*

How many miles away is the lightning when thunder is heard 22 seconds after the flash, the temperature of the air being 70° Fahr.?

Why are musical instruments provided with sounding-boards? *So as to increase the area of the vibrating surface, and thus gain in intensity.* If the intensity be increased in this way, remember that the duration of the sound is diminished.

MAGNETISM.

NATURAL AND ARTIFICIAL MAGNETS.

Lodestones.—It was known to the ancients that a certain black mineral possessed the power of attracting small pieces of iron or steel. This mineral was an ore of iron, called by the Greeks *magnes*, from Magnesia, the name of a city in Asia Minor, near which it was procured. Specimens of the same magnetic iron are now found in various parts of the earth and are known as natural magnets, sometimes lodestones (*leading-stones*), because when freely suspended they tend to point north and south.

The pupil may prove this fact by hanging a piece of lodestone in a stirrup of copper wire. After oscillating for a few seconds, it will come to rest with its length in a northerly and southerly direction.

Artificial Magnets.—If a bar or other piece of steel be rubbed with a natural magnet, it will acquire the properties

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NOTE.—With the apparatus shown above, the fundamental principles of magnetism may be illustrated. Nos. 1 and 7 are horseshoe-magnets; No. 2 shows bar-magnets; No. 3, a piece of steel watch-spring; No. 4 is a magnetic needle mounted on stand; No. 5 is a sifter for iron-filings (made cheaply by removing the bottom from a tin box and soldering on a piece of fine wire gauze in its place); No. 6 is a pocket compass; and No. 8, a piece of lodestone. This outfit may be obtained of any dealer in electrical apparatus.

of the latter and become itself a magnet, attracting iron filings, needles, etc. The power of communicating magnetism from one body to another may be applied indefinitely; the same magnet may be used for this purpose many times without losing its strength.

A piece of steel to which magnetic properties have been imparted is called an Artificial Magnet.

Natural magnets are now seldom used except as curiosities, because artificial magnets are cheaper, and it is much easier to make them of convenient forms than is possible in the case of a brittle mineral like lodestone.

Varieties of Artificial Magnets.—There are several kinds of artificial magnets, called from their shape Bar-Magnets, Horseshoe-Magnets, and Magnetic Needles (see figure, page 419). It is possible, however, to magnetize a piece of steel of any other shape, and for special purposes magnets have been made in the form of spheres, disks, and rings.

A magnet is usually furnished with a piece of soft iron of proper size and form to develop and preserve its full attractive power, and this is called the Armature, or keeper.

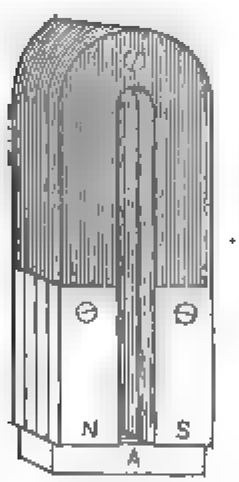


Fig. 300. Compound Horseshoe-Magnet, with Armature in place.

Magnetic needles are light magnetic bars, generally lozenge-shaped, delicately pivoted, as in the pocket compass, or suspended by a strand of silk. The needle is sometimes placed horizontally on a floating cork for purposes of experiment.

Compound Magnets.—Let the pupil tie a number of knitting-needles in a bundle and then rub them thoroughly with a magnet in one direction. On testing the needles separately, it will be found that only those which were on the outside of the bundle have become strongly magnetized. This is because the magnetic effect does not penetrate very far from the outer surface.

The same fact is true of a solid bar of steel. In order,

therefore, to make a large powerful magnet, a number of steel bars are magnetized separately and then riveted together. A magnet made in this way is called a Compound Magnet, and may have either the bar or horseshoe form.

PROPERTIES OF MAGNETS.

Attraction.—If a small iron nail be brought in contact with a natural or artificial magnet, it will be attracted by the latter and may be lifted from the table. This power of attracting iron is the most important and characteristic property of the magnet, and almost all the useful applications, as well as the scientific experiments of magnetism, are based upon it.

Iron is not the only metal attracted by the magnet; cobalt and nickel are similarly influenced. The pupil may experiment with a bar-magnet on different substances—paper, leaves, sawdust, steel-filings, pieces of lead, copper, and zinc—and thus ascertain for himself what bodies are magnetic.

Magnets not only attract magnetic substances, but are also attracted by them in turn. A bar-magnet suspended by a thread is drawn toward a stationary piece of iron.

Although the attractive power of lodestone was known in antiquity, it was regarded merely as an interesting phenomenon and never utilized. Pliny informs us that Ptolemy Philadelphus proposed to build a temple at Alexandria, the ceiling of which was to be of lodestone, that its attraction might hold an iron statue of his queen Ar-sin′-o-e suspended in the air. Death prevented Ptolemy from carrying out his design; but St. Augustine, at a later day, mentions a statue thus actually held in suspension in the temple of Se-ra′-pis at Alexandria.

Attraction through Bodies.—A magnet attracts a nail through a board, book, or plate of glass, just as if nothing intervened. Through an iron plate, however, the attraction is reduced or entirely checked.

Magnetic attraction is thus transmitted through glass, wood, or other non-magnetic bodies, very nearly as well as

through air. The iron plate, however, takes up the magnetic effect, being itself attracted, and so prevents the force from passing through and reaching the nail.

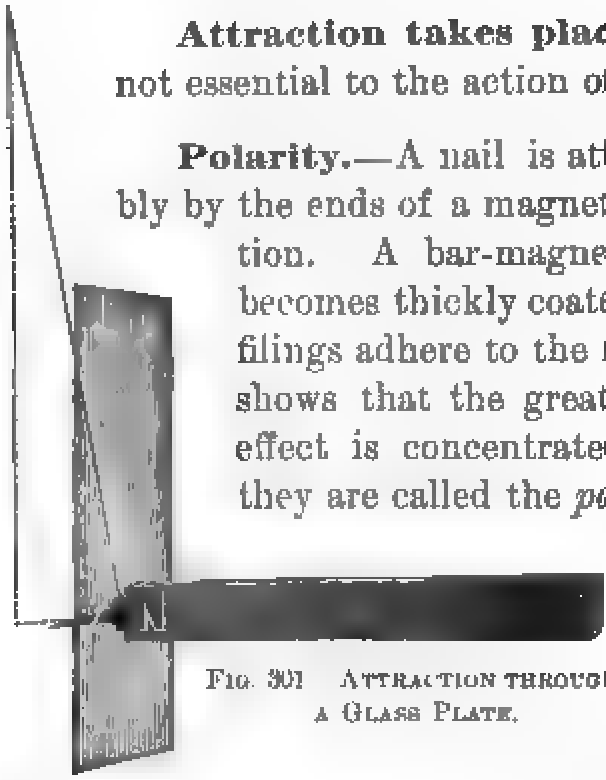


Fig. 301 Attraction through a Glass Plate.

Attraction takes place in a Vacuum; air is not essential to the action of a magnet.

Polarity.—A nail is attracted much more forcibly by the ends of a magnet than by the middle portion. A bar-magnet dipped in iron-filings becomes thickly coated at its extremities; few filings adhere to the middle of the bar. This shows that the greater part of the magnetic effect is concentrated at the two ends, and they are called the *poles* of the magnet.

The exact parts of the poles where the effects are the strongest are not at the extreme ends of the magnet, but a little distance inward. From these poles the attractive power decreases almost uniformly toward the center, where it is reduced to nothing. The line of disappearance is called the neutral line of the magnet.

Fig 302.—Magnet dipped in Filings.

The attractive power of different parts of a bar-magnet may further be tested by means of the magnetic pendulum, an iron ball suspended by a thread from some convenient point.

North and South Poles.—One particular pole of the needle, if suspended by a string, or pivoted as in the ordinary pocket compass, will always be found to turn toward the north. This is therefore called the north-seeking, or north pole; the other, the south-seeking or south pole.

The poles of a magnet are usually distinguished by the letters N and S; but sometimes the north pole has merely a line filed across it, and is called the marked pole. It is also

distinguished as the positive (P) or + pole, in which case the opposite end is styled the negative or — pole.

Considerable confusion exists in regard to the names of the magnetic poles. In this country and in England the poles are generally distinguished as stated above; but the French call the pole which points north a south pole, while the Chinese attach the *fleur-de-lis* to the south instead of the north pole. The north pole is sometimes painted red and the south pole blue.

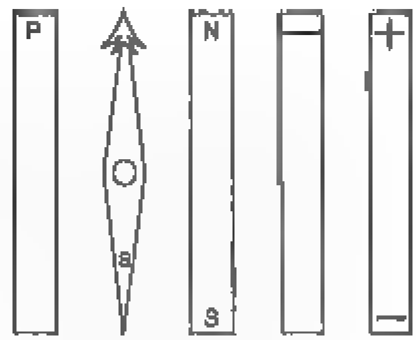


FIG. 303.—DIFFERENT METHODS OF MARKING THE POLES OF MAGNETS.

QUESTIONS.—State what you know of the history of Magnetism. What is the origin of the word? What is lodestone? Describe its properties. Into what two classes are magnets divided? Why are artificial magnets preferable to natural stones? How are artificial magnets made? Name several varieties of artificial magnets. What is an armature? Explain the principle of the compound magnet.

Mention the chief properties of magnetism. Describe the phenomena of attraction. Is iron the only substance attracted by a magnet? What use was made of magnetism in antiquity? What effect on attraction has a board or piece of glass interposed between the magnet and the magnetic body? Does attraction take place in a vacuum? How can you prove your answer? What would be the probable effect on a watch if a bar-magnet were brought near it? *The balance-wheel would be attracted, and the watch would stop.* (Watches are now manufactured whose entire escapement is made of metals which are by nature insensible to magnetism.)

Explain polarity. Account for the appearance of a magnet dipped in iron filings. Where does the greatest attractive force reside in a magnet? Where the least? In what different ways are the north and south poles of a magnet distinguished? Can you think of other amusing experiments with the magnet? (Suggestions: Floating objects may be cut out of cork and pieces of steel imbedded in them. A well magnetized steel bar concealed in a piece of a bamboo cane will serve as a magic magnetic wand, with which floating figures may be attracted and repelled, etc.) Can you contrive a way of causing a threaded needle to appear suspended in the air?

LAWS AND PRINCIPLES OF MAGNETISM.

Law of Attraction and Repulsion.—If a compass and a magnet be brought close together, the two north poles and the two south poles will repel each other; but the south-seeking pole of the magnet will attract the north-seeking

pole of the compass-needle, and *vice versa.* This fact gives rise to the general law: Like poles repel each other, unlike poles attract each other.

Balance a bar-magnet with weights on a pair of scales. Beneath its positive pole bring the positive pole of another magnet, and the scale containing the bar will rise, owing to the repulsion of the like poles. Substitute the negative pole, and the scale will descend, owing to the attraction of the unlike poles.

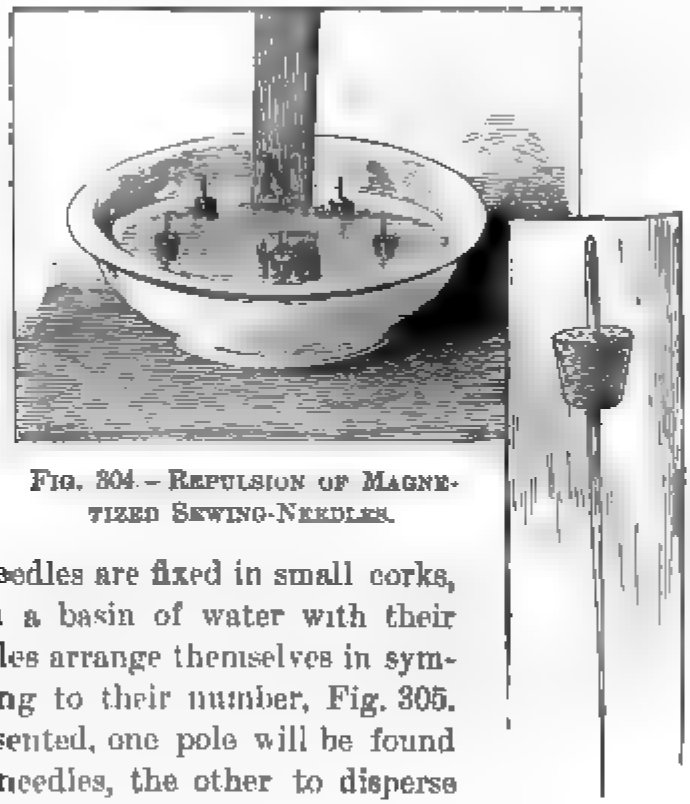


FIG. 304.—REPULSION OF MAGNETIZED SEWING-NEEDLES.

The mutual repulsion of similarly magnetized bodies is interestingly illustrated by Prof. Mayer's floating magnets. A number of magnetized sewing-needles are fixed in small corks, so that they will float in a basin of water with their points down. The needles arrange themselves in symmetrical groups, according to their number, Fig. 305. If a bar-magnet be presented, one pole will be found to attract the floating needles, the other to disperse them. (Study Fig. 304.)

The opposite action of different poles may be further illustrated by suspending a steel key from the north pole of a bar-magnet, and moving along the latter a second magnet of the same size, with the contrary pole presented. The key remains suspended until the two poles are sufficiently near to neutralize each other's action, when it falls.

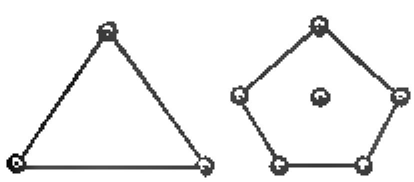


FIG. 305.

FIG. 306.—NEUTRALIZING ACTION OF OPPOSITE POLES.

The Astatic Needle.—The tendency of two exactly equal magnetic needles to point north may be neutralized

by supporting them, with their poles in opposite directions, on the same pivot, in the same vertical plane. An instrument thus constructed is called an Astatic Needle (*not standing* in a north and south line); it does not seek the north pole, but remains in the position in which it is placed.

The Second Law of magnetism is as follows: The force exerted between two magnetic poles, whether attraction or repulsion, is directly proportional to the product of their strengths, and inversely proportional to the square of the distance between them.

The experimental proof of this law is measurably difficult, because it requires instruments for accurately measuring the amount of the force and the distance; but a few trials will convince any observer that the force between two poles two inches apart is only about one quarter as great as at a distance of one inch.

The Two Poles Inseparable.—A piece of watch-spring, even though magnetized by rubbing it with only one pole of a magnet, always acquires two poles, one north and one south. If the magnetized watch-spring be broken into a number of pieces, each piece will be found to have two poles, and this is the case however small the pieces may be. Both parts of this experiment demonstrate the principle that a magnet can not be made with one pole only. Two poles, one south and the other north, must always exist together, and must also be of equal total strength, though this strength may be differently distributed.

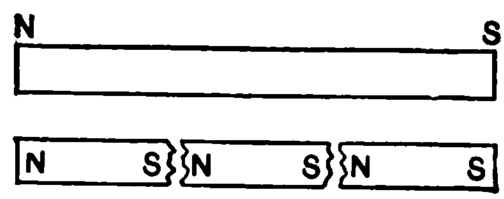


FIG. 307.—POLARITY IN PIECES OF A MAGNET.

The absolute inseparability of the two poles is one of the most inherent and unchangeable facts in magnetism. It is explained on the principle that the power of a magnet resides in its molecules, whose north poles are all turned in one direction and the south poles in another, so that the poles of magnetic elements intermediate between the extremities of the magnet neutralize one another. The magnetic force is thus free only at the + and — ends of the magnet.

If the broken pieces of watch-spring be joined again so as to form

a single magnet, it will be found that only the original poles exist, the intermediate poles having disappeared.

Magnetic Induction.—A piece of soft iron, like a nail, when brought close to a strong magnet, even if not in contact with it, becomes itself a magnet and will attract a tack (see Fig. 308). This magnetizing action of a magnet on other bodies is called Induction. The polarity induced is such that an unlike pole is created in the end of the magnetic substance nearest the inducing pole of the magnet, and a like pole in the opposite end, as shown in the figure.

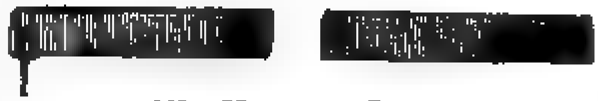


FIG. 308.—MAGNETIC INDUCTION.

The interposition of a sheet of paper or glass, the hand, or any non-magnetic substance, between N and S, will not interfere with the inducing power of the magnet.

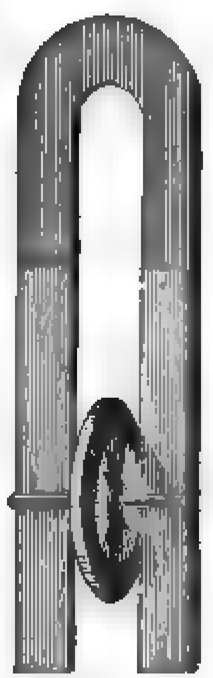


FIG. 309. THE ROLLING ARMATURE MAGNET.

Induction accounts for the attraction of a piece of soft iron. An unlike pole is first induced in the iron and then attracted; and this effect is greater than the repulsion of the like pole at the opposite end, on account of the distance of the latter. Hence the general result is attraction.

Soft iron armatures become magnets by induction, and then by induction react upon their magnets, thus strengthening the power of the magnets themselves. The rolling armature, shown in Fig. 309 attached to a U-shaped magnet, is attracted with such force that when the magnet is held in a vertical position and the armature descends, instead of falling off it turns the poles and is carried by its momentum some distance up the opposite side.

The Magnetic Chain.—A number of pieces or rings of iron may be suspended from a magnet in the form of a chain, each individual in the series becoming by induction a temporary magnet. Carpet-tacks may be used in making the experiment. If the tack in contact with the magnet be

taken in the hand and the magnet withdrawn, the tacks at once lose their magnetism and fall to the ground.

It will be found that a given magnet will support a certain number of tacks in the form of a chain; but when a second magnet is placed beneath the chain, so that its south pole is under the north pole of the original magnet, the magnetic power in the poles of the several tacks will be increased by induction, and the chain may be lengthened by the addition of other tacks.

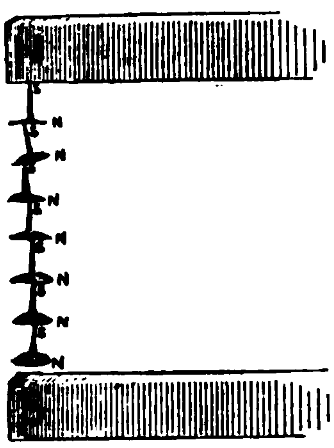


FIG. 310.—THE MAGNETIC CHAIN.

Let the pupil explain what will take place if the lower magnet be turned round.

Making of Artificial Magnets.—There are various methods of making artificial magnets. By simple rubbing with a piece of lodestone, in the direction of the line joining its poles, a steel bar may be magnetized. The method by single touch consists in rubbing the bar with the pole of a permanent magnet, care being taken that the strokes are delivered in the same direction.

In magnetization by double touch, a bar of hard steel is placed horizontally, and the opposite poles of two strong magnets are then applied to the middle of the bar and drawn apart to the ends. This is repeated several times; the bar is then turned, and the other side treated similarly. It will now be found to be strongly magnetized.

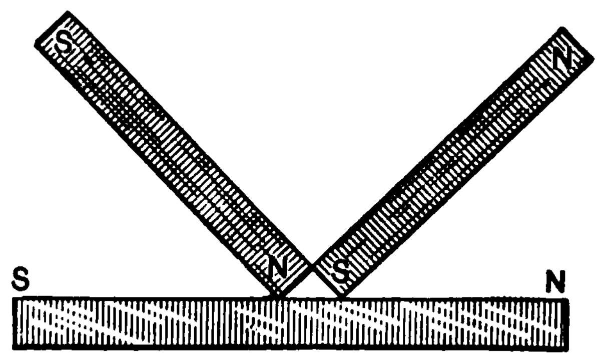


FIG. 311.—MAGNETIZATION BY DOUBLE TOUCH.

Retentivity.—A hard steel bar, magnetized as described in the last experiment, retains a large part of the magnetism. Soft iron treated in the same manner retains little or no magnetism. Hence we say that hard steel has great magnetic retentivity, or coercive force, and soft iron very little. For this reason, when we wish a magnet to retain its power permanently, we make it of hard steel.

Lifting Power.—A horseshoe-magnet will lift a load three or four times as great as a bar-magnet of the same weight (see Fig. 312). This is because both poles of the former act instead of one; and, furthermore, each pole increases the effect of the other by induction.

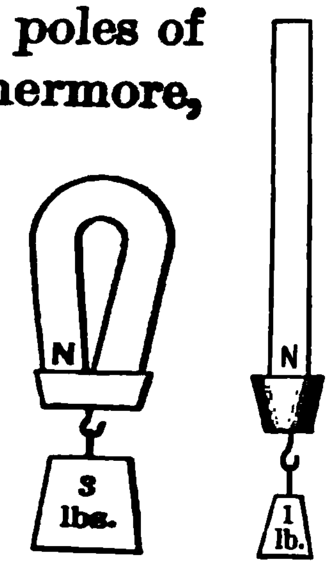


FIG. 312.—LIFTING POWER OF BAR AND HORSESHOE MAGNET

This lifting power is the simplest test of the strength of a magnet. A good magnet weighing one pound should lift twenty pounds. Small magnets will carry relatively more weight than large ones. Newton is related to have worn in his ring a piece of lodestone weighing only three grains, but with a carrying power of 746 grains. Two hundred pounds per square inch of surface is about the greatest force that can be exerted.

Preservation of Magnets.—Magnets may in various ways be weakened or entirely lose their power. The following precautions should therefore be observed in order to keep them in good condition:

1. Do not allow a horseshoe-magnet to remain for any length of time without its armature. Bar-magnets are generally weak because they are not usually provided with keepers. Hence they should be kept either in pairs, with the unlike poles together, or else with bars of soft iron laid alongside to act as keepers.

2. Do not put two magnets away with their like poles in contact, because each will tend to weaken the other by inducing in it the opposite kind of magnetism.

3. Do not leave a magnet with its south-seeking pole pointing north, because in this position its polarity may be weakened or even reversed by the magnetism of the earth.

4. Do not allow a magnet to receive rough usage. A blow or fall will disturb the magnetic arrangement of the molecules.

5. Do not heat a magnet, as heat perceptibly weakens it. The most powerful magnet becomes absolutely demagnetized at a red heat, and remains so after cooling. Magnetize a piece of knitting-needle, then raise it to a red heat, and you will find that it has entirely lost its magnetism.

Lines of Force, and Magnetic Field.—If a large card or glass plate be laid horizontally on a bar-magnet and

fine iron-filings be dusted upon it with a sieve or "colander" (see No. 5, page 419), the filings become arranged by in-

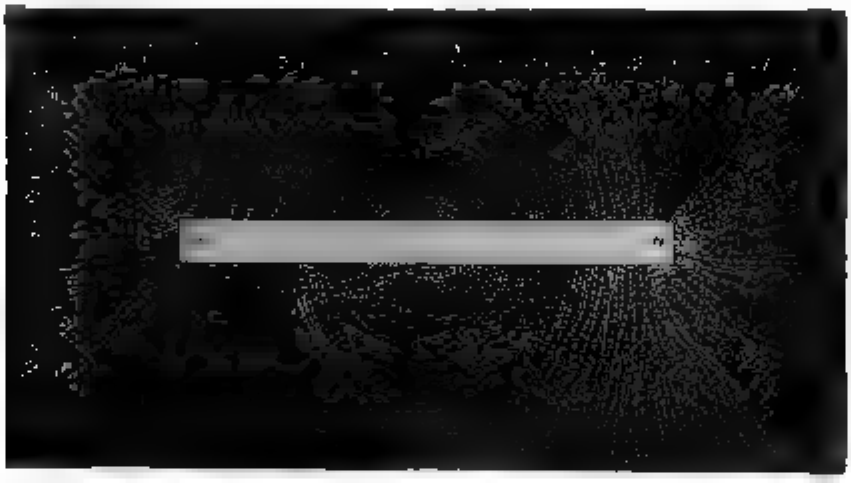


FIG. 313. LINES OF FORCE IN CASE OF BAR-MAGNET.

duction in peculiar curves, the formation of which is aided by gently tapping the card or glass.

These curves may be made permanent by coating the glass with paraffine or varnish and allowing it to harden before the filings are sifted upon it. After the curves are formed, the paraffine or varnish is softened by heating the plate over a spirit-lamp, or warming it in an oven, and the filings sinking into the film, the curves become fixed when the plate cools. Plates thus made may be used as lantern-slides.

The curves described above indicate the direction and intensity of the magnetic force, and from them we derive the idea of lines of force. It should be remembered, however, that lines of force do not really exist, as the actual forces themselves are not distributed in lines, but fill the entire space around the magnet, which space is called the Magnetic Field.

FIG. 314.—LINES OF FORCE BETWEEN UNLIKE AND LIKE POLES.

The difference between the curves produced by unlike and like poles is shown in Fig. 314. An inspection of the lines of force greatly assists the mind in conceiving how

attraction takes place in the first case, and repulsion in the second. Each particle of iron is made a magnet by induction and places its longest diameter in the line of force that passes through it; and along each line of force a magnetic chain is formed in accordance with principles already explained.

Nearly fill one of your test-tubes with iron-filings and then stroke it several times with a powerful magnet. The particles of iron will be seen to set themselves in the direction of their lengths.

QUESTIONS.—State the law of Attraction and Repulsion. By what experiments can you illustrate it? Give the details of Prof. Mayer's experiments with floating magnets. If you lay a bar-magnet on a table with its N pole projecting over the edge, and allow an iron nail to cling to its under side, state and explain what will occur when the S pole of a second magnet is brought over and near the N pole of the first. Describe the astatic needle.

What is the second law of magnetism? Its experimental proof? Account for the fact that each piece of a magnet has its own poles. Explain Magnetic Induction. How does it account for the attraction of iron? How, for the strengthening effect of the armature? Why is less force required to pull a small iron rod away from the poles of a powerful horseshoe-magnet than to detach a thick piece of iron? Describe the rolling armature; the magnetic chain; different methods of making artificial magnets. How would you magnetize a sewing-needle so that the point shall be a north-seeking pole?

What is Retentivity? Suppose that two rods are handed you, one of iron and the other of steel; also, a compass-needle and a bar-magnet. Describe experiments whereby you can ascertain which is the iron rod. Compare the lifting power of horseshoe and bar magnets. What methods are suggested for preserving the strength of magnets? Give reasons in each case. What are lines of force? Describe the magnetic field. If two long iron wires are suspended from the same pole of a magnet, will they hang parallel? Why?

THE EARTH'S MAGNETISM.

The Earth a Great Magnet.—The direction assumed by a magnetized needle is called the Magnetic Meridian. The fact that the needle places itself in the magnetic meridian shows that the earth acts as if it contained a great magnet, some of whose lines of force pass along the ground, while others lie entirely within the earth itself.

The action of the earth on the compass-needle is exactly the same as that of a permanent magnet. A steel bar is

temporarily magnetized by induction when pointed toward the magnetic pole of the earth, as it is when brought near the pole of a magnet; if struck a blow in the direction of its length when so pointed, it remains permanently magnetized. (Let the pupil make these experiments.)

Magnetic Pole of the Earth.—The magnetic needle does not generally point exactly toward the true north. If we carefully compare the direction in which the compass-needle points with the true north line, determined by the north star, we shall find that the two do not in most localities correspond.

This shows that the magnetic pole of the earth, toward which the needle points, is not situated at the same place as the geographical pole. A negative magnetic pole, however, must be in the neighborhood of the geographical north pole in order to attract the + pole of the needle.

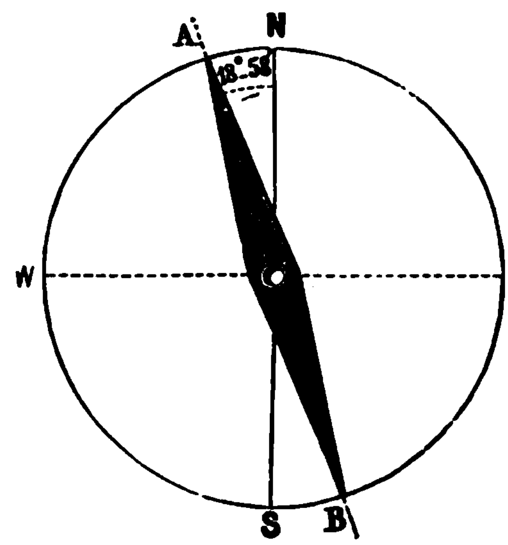


FIG. 315.—DECLINATION.

The angle between a true north and south line and the direction of the needle is called the Declination of the Compass. It amounts to twenty degrees, or even more in some localities; while, in the absence of local disturbance, there is no declination at places on a line with the true and the magnetic pole.

Declination is subject to variations extending through long periods of years. At London, where magnetic observations have been made since 1580, the declination was in that year 11° 17′ E.; in 1657, it had become reduced to nothing, and the compass-needle pointed to the true north. In 1816, it reached its greatest value of 24° 30′ W. In 1888, it was only 17° 40′ W.

Magnetic Dip.—If a needle be balanced so as to be horizontal when suspended by a thread, and then be magnetized, it will not only place itself in the vertical plane of the magnetic meridian, but will point downward at places

in the northern hemisphere. The angle at which it is inclined to the horizon is called the Dip or Inclination of the needle, and is due to the fact that the earth is round, and the magnetic pole is therefore not on a horizontal line with the compass, but below such a line.

This is illustrated in Fig. 316, in which the line A B represents the true axis of the earth, P the magnetic pole, N S a dipping-needle, pointing at the pole, and C D a horizontal line through the center of the needle. The angle between the needle and the line C D is the dip.

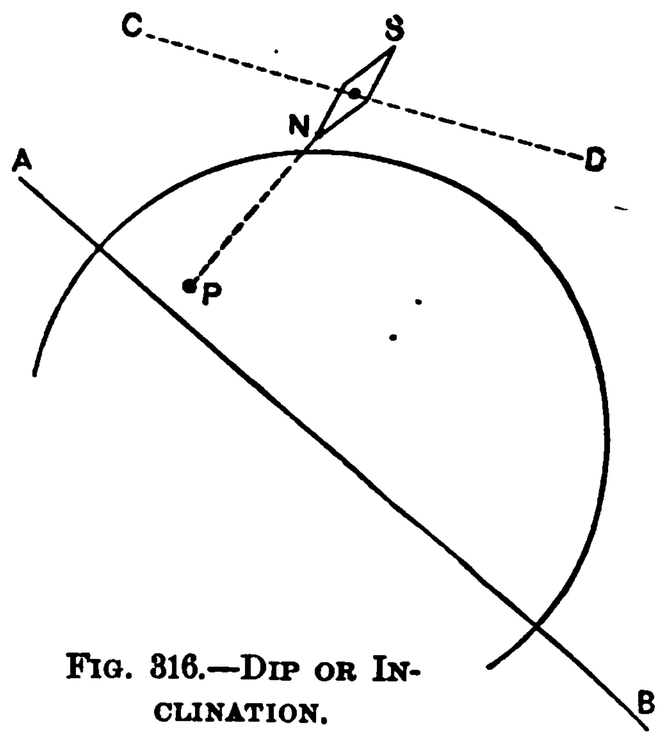


FIG. 316.—DIP OR INCLINATION.

A sphere of lodestone causes a small needle carried over its surface to dip, thus illustrating the action of the earth.

Useful Applications of Magnetism. — Permanent magnetism has few practical applications. Magnetism when produced by electric currents (see page 506), is much more powerful and more conveniently applied.

Almost the only use made of the permanent magnet is in the Mariner's Compass. This consists of one or more magnetic needles attached to the lower face of a circular card, delicately pivoted, and generally immersed in a liquid so as to decrease the pressure upon the pivot. The circumference of the card is divided into degrees, and also into thirty-two "points of the compass." It is supported in such a manner that the card may always be horizontal, notwithstanding the motion of the vessel. The needles remain in the magnetic meridian, with which a ship's course may readily be compared.

The Mariner's Compass was, according to some authorities, invented in China, and made known to Europeans through the instrumentality of the Mohammedan Arabs. The first mention of the use

of the magnetic needle in Christian Europe occurs in a curious Provençal poem, written in 1190. Early accounts of the instrument describe it as a simple iron needle magnetized and placed on a pivot, or floated on a cork in a vessel of water, in either case free to turn in any direction.

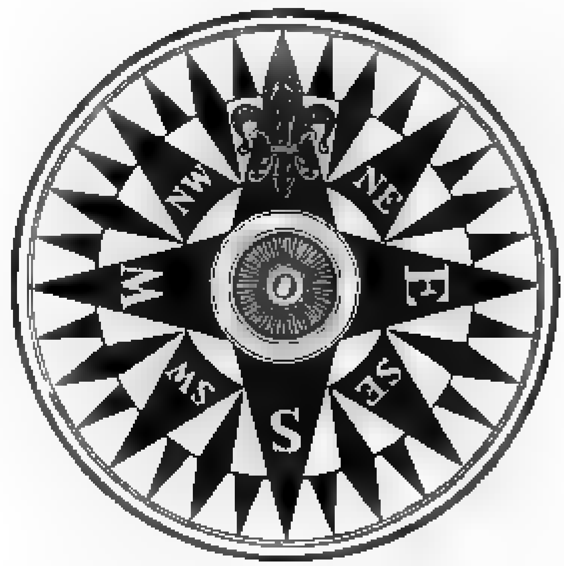


FIG. 317. COMPASS-CARD.

The magnetism induced in iron ships by the action of the earth's force, in connection with the constant hammering during the process of building, causes a serious deviation of the compass, for which allowance has to be made in determining the true direction.

Permanent magnets have been used for separating magnetic iron-ore from the sand with which it occurs. The surgeon sometimes has recourse to the magnet to remove from the eye particles of steel or iron so situated as to render their extraction with ordinary instruments difficult, if not impossible. To determine the presence of steel in any of the tissues, a powerful magnet is held for fifteen minutes on the injured part, thus magnetizing the impacted fragments. Their exact location may then be ascertained by the dip of a delicately suspended needle. Sewing-needles, accidentally forced into the flesh, have been brought within reach by the persistent action of strong magnets.

QUESTIONS.—What is the Magnetic Meridian? The behavior of the compass-needle proves what in regard to the earth? If you were required to make a model illustrating the magnetic properties of the earth by putting a bar-magnet inside a ball of clay, show by a sketch how you would place the magnet, and explain how the magnetic properties of the model would correspond with those of the earth. Explain Declination; Dip. To what variations is declination subject?

Describe the Mariner's Compass. Relate what is known of its history. How is it affected by the plates of iron ships? How are such plates magnetized? What then has to be made in determining true direction? For what purpose has the magnet been utilized by the mineralogist? By the surgeon?

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Why does not the needle in your pocket-compass dip?

State what you think would be the effect of adding daily a little to the weight which a magnet supports. Of overloading a magnet.

Why does not a freely floating needle move bodily toward the north magnetic pole? *Because the forces that have brought it into the magnetic meridian are then equal, opposite, and in the same line.*

Why is a compass untrue in the neighborhood of iron or steel?

If a horseshoe-magnet be placed near a compass-needle, it will move the needle a little way round; but if a piece of soft iron be laid across the poles of the magnet, the needle will move back toward its natural position. Explain this.

If you have three equal bar-magnets without keepers, how would you arrange them so that when not in use they may preserve their magnetism?

Explain magnetic polarity, and the law of magnetic behavior.

How may the polarity of two needles of equal power be destroyed?

What are the magnetic poles of the earth?

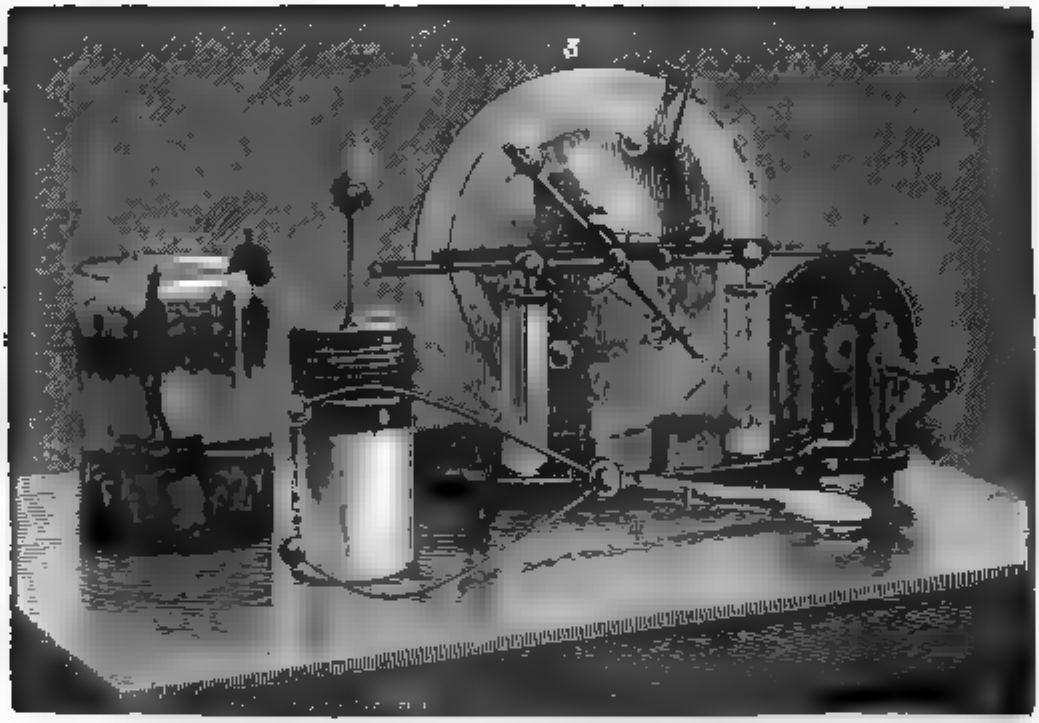
What would be the position of the needle at the north magnetic pole? *It would stand vertical, with its north pole toward the earth.* Describe its position at the south magnetic pole.

Illustrate the variations to which Declination is subject.

What is a line of no variation? *A line along which the declination does not vary.* Columbus discovered such a line east of the Azores (see page 8, Appletons' Physical Geography). Aware of the change in the direction of the needle, with a change of place, it seemed to him as if he were indeed "entering a new world" in which the very laws of Nature were at fault.

Is the cause of the earth's magnetism understood? *It is not.*

It has often been attempted to make magnetic "perpetual-motion machines." The usual plan has been to attach a number of pieces of iron to the rim of a wheel revolving near the poles of a magnet, and to place between the magnet and the wheel a magnetic screen, covering the half of the wheel below the magnet. In this way, the pieces of iron on the upper side of the wheel would be drawn toward the magnet; but it was supposed they would pass behind the screen upon reaching the point in their path nearest the magnet, and would then cease to be attracted. Hence they would freely move away from the magnet on the lower side of the wheel. Thus there is apparently quite a strong tendency for the wheel to keep on revolving in one direction perpetually, or until the machine wears out. There is, of course, a fallacy in this, as in all other "perpetual-motion machines" (turn to page 148). What is it? *We have learned that attraction takes place through all non-magnetic substances almost equally well; therefore, there is no known screen or shield for magnetism except iron, or some other magnetic material. But such a screen takes up the lines of force itself, and would therefore weaken the attraction of the magnet for the upper pieces of iron on the wheel. Even if a perfect magnetic shield were found, a machine of this kind would not work, because the magnetic lines of force would curve around behind the shield* (see page 429) *and hold the lower pieces of iron back exactly as much as the upper pieces are drawn forward, and hence the wheel would stand still.*



ELECTRICITY.

ELECTRICAL PHENOMENA.—POTENTIAL.

Electricity and Heat compared.—When we are subjected to variations of temperature, as near a furnace or a load of ice, we experience sensations and observe phenomena which we attribute to an agent called Heat.

Neighboring bodies at times also differ from one another in a manner which produces other phenomena, and these we refer to an agent known as Electricity. The phenomena of electricity were first observed in the clouds as thunder

NOTE.—In the illustration above are shown a typical electrical machine (3), condenser (2), and discharger (4), with a gravity-cell (1), the principle of action in the case of each generator of electricity being explained in the following chapter. A class provided with these articles (furnished by all prominent dealers in electrical instruments), and such other simple apparatus as can easily be improvised in accordance with directions given in the text, will be enabled to perform the fundamental experiments in electricity. It is recommended that there be added a glass rod and a rod of shellac or vulcanite for excitation, a cat's skin as an exciter, a dozen pith-balls, a few gold leaves, and a yard or two of copper wire. Cheaper electric machines may be purchased or constructed by the ingenious pupil; but the Toepler-Holtz (shown above) is by far the most satisfactory, giving brilliant discharges and working under all atmospheric conditions.

and lightning. They were produced artificially by rubbing amber (in Greek, *electron*), perhaps 600 years B. C.; but Benjamin Franklin first showed that the electricity of amber was identical with that of the clouds.

Differences of temperature are continually obliterated by the transmission of heat from hot bodies to neighboring cooler ones. Electrical differences are more quickly equalized, hence their phenomena are less frequently noticed in Nature, unless instrumental methods of observation are used.

The savage sees little of heat except in the fluctuations of the weather and in his camp-fire. In civilized life, we meet it in furnace and forge, in our gas-flames, in the bearings of machinery, in chemical reactions, and in thousands of cases where it is used in the arts.

During the last ten years, electrical phenomena have become more commonly known through similar applications of electricity.

Potential.—When neighboring bodies differ in such a way that electrical phenomena are observed in the region between them, the bodies are said to be *at different potentials.* Two clouds which differ sufficiently in potential will be connected by a flash of lightning. If a stick of sealing-wax or a cake of resin be rubbed with a piece of flannel or a cat's skin, the two bodies will assume different potentials. They are said to be *electrified*, as a body of high temperature is said to be heated.

PROPERTIES OF ELECTRIFIED BODIES.

An Electrified Body brought near to any other uncharged body of different potential will *attract* it. If the second body is easily movable, it will be drawn toward the first. Small pieces of paper, pith-balls, a soap-bubble, a toy balloon, or a light pendulum of any material, will, under such circumstances, be attracted; and a water-jet from a siphon or hydrant will be deflected into a curve instead of falling in a vertical line (see Fig. 319). If a hard rubber pen-holder or large glass tube be vigorously rubbed with a

silk handkerchief, it will serve as the electrified body in the experiments just described.

In a dark room, flashes of light may be seen during the rubbing of the two bodies, accompanied with a crackling sound; and by presenting the knuckle to the electrified body, faint sparks are sometimes observed. A peculiar odor is perceived when such sparks are produced; in the case of lightning which strikes the earth, it is always noticed by persons in the vicinity. This odor is that of *ozone*, a colorless gas formed from the oxygen of the air.

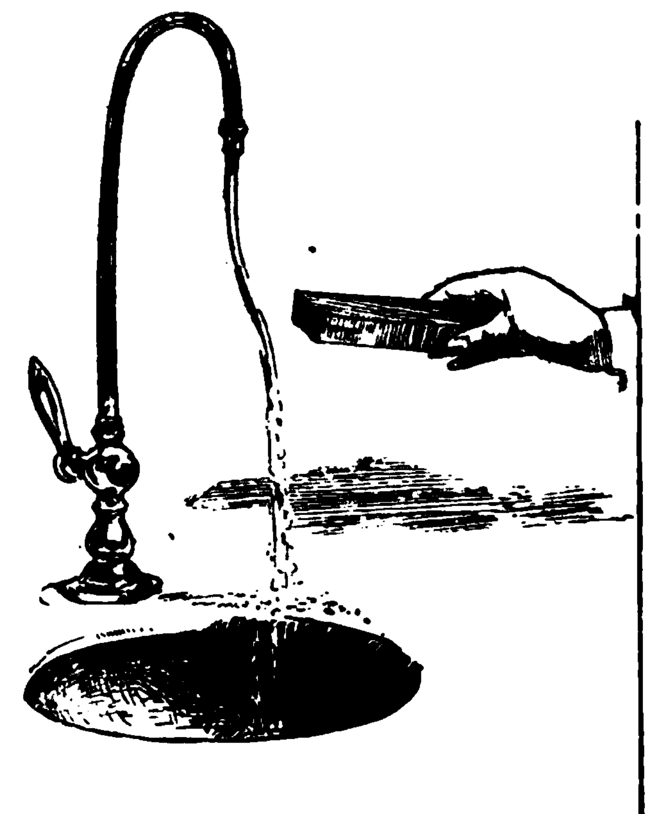


FIG. 319.—DEFLECTION OF WATER-JET.

The face when brought near the excited body feels as if a cobweb were in contact with it—a sensation really due to air-currents which are repelled from the body against the face.

Attractions and Repulsions.—If a pith-ball hung on a silk fiber is allowed to touch the attracting body, it will, after a few moments, be repelled, as shown in Fig. 320. If the ball be followed up by the electrified body, it will be continually repelled (see page 53). Grasp the pith-ball in the hand. The electricity will be conducted away, and it will then be attracted as before (Fig. 321). If the pith-ball be gilded, it will be repelled the instant it touches the electrified body.

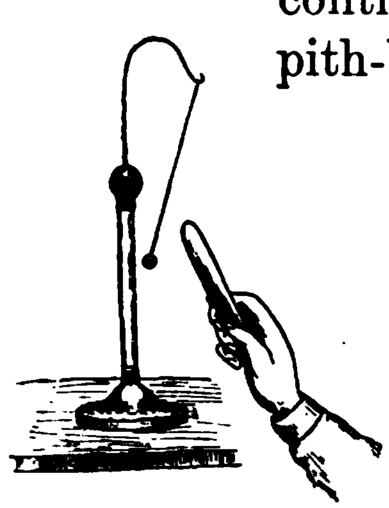


FIG. 320.—REPULSION.

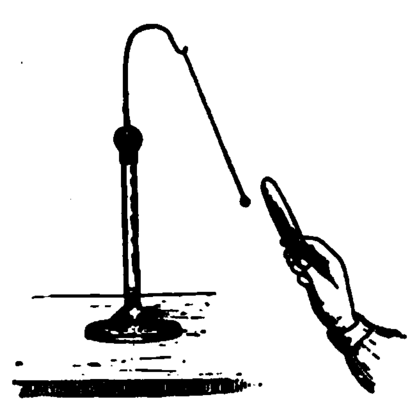


FIG. 321.—ATTRACTION.

Hang a small glass tube in a wire stirrup, the ends of which are tipped with globules of solder, and suspend the whole on a silk fiber, as shown in Fig. 322. Another glass tube which has been excited by friction with silk will attract either end. Allow the tubes to come in

contact; repulsion will not follow. If, however, a metal rod be substituted for the swinging glass tube, either end will be attracted; but if contact is allowed to take place, the metal rod will finally be repelled. The end which was not touched will also be repelled.

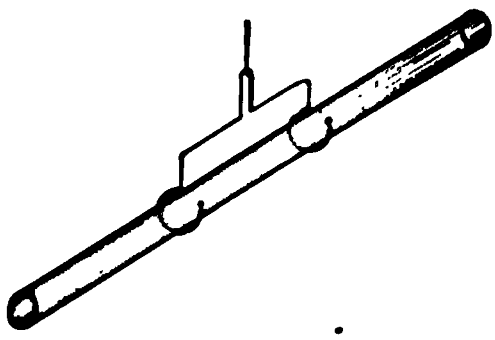


Fig. 322.—Glass Tube in Wire Stirrup.

Coat a glass rod with an alcoholic solution of shellac, ignite the shellac, and while the tube is hot cover it with tin-foil. It will now behave like the metal rod.

Conduction of Electricity.—Apparently the electricity is communicated from the attracting to the suspended body. If the suspended body is metallic or has a metallic coating, the electricity is quickly diffused over the whole surface; but, in order to electrify the glass tube, every part of it must be brought in contact with the electrified body. The metal is said to *conduct* the electricity.

Bodies that transmit electricity freely, like metals, living plants and animals, and water, are known as Conductors; those that do not, as silk, glass, feathers, hard rubber, and air, are called Non-conductors or Insulators.

Electrify a stick of sealing-wax by rubbing it with flannel, and present it to a suspended stick of sealing-wax which has been similarly treated. The sticks will repel each other. Two glass rods rubbed with a silk handkerchief will also repel each other; but an electrified glass rod and an electrified stick of sealing-wax will attract each other. Either may be suspended in the wire stirrup, and the other may then be presented to it.

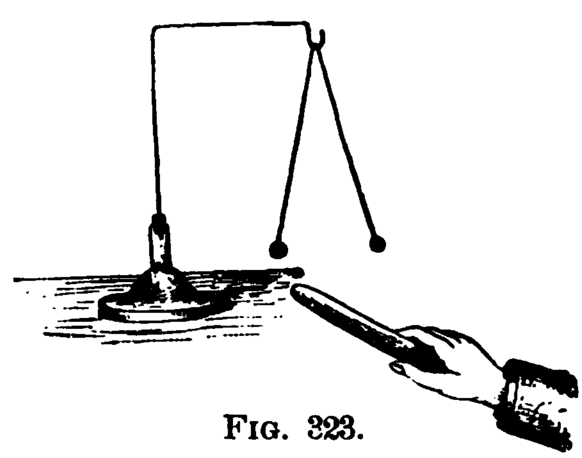


Fig. 323.

The pith-ball, when unelectrified, will be attracted either by the glass rod or the stick of sealing-wax. Electrify it by allowing it to come in contact with either. That body (for example, the glass rod) will then repel it. The other body (in this case the sealing-wax) will then attract it.

Suspend two gilded pith-balls on silk fibers from a common sup-

port, so that they hang in contact with each other. Then electrify them by contact with the excited glass rod. They will immediately fly apart (see Fig. 323). Bring the glass rod up under the two balls, and they will be repelled more widely. If the excited sealing-wax be placed in the same position, the balls will then be drawn together,

Present the flannel used in rubbing the sealing-wax, and the balls will diverge more widely. The flannel behaves like the glass rod, and repels when the sealing-wax attracts.

In a similar way it may be shown that when any two unlike bodies are rubbed together they both become electrified, and that when one will attract the other will repel a third electrified body.

In some cases it is necessary to insulate the bodies on supports of glass or hard rubber, to prevent the escape of the electricity. This is the case with flannel and silk, which become slightly moist from the hand; also with a metal tube, which must be provided with a glass handle. Why?

When the two bodies which have been rubbed together are held in contact, they act equally in opposite directions on any third body. The resulting force is zero.

Positive and Negative Electricity.—If the electricity of the two bodies is added together, the bodies become *un*electrified. These charges of electricity behave like equal positive and negative quantities.

On this account, these electricities are called *positive* and *negative* electricities. No reason is known for calling one of them positive rather than the other. The electricity of glass when rubbed with silk is called positive, and that of resin or sealing-wax negative. A body charged with + electricity is said to have a + potential, while a body negatively charged has a — potential.

Any two bodies which differ even in temperature, will when rubbed together, become not only heated, but also electrified.

Potential Series.—In the following list, the substances are named in such order that if any two of them are rubbed

together the one first named in the series becomes positively electrified, while the other becomes negatively electrified:

1. Cat's skin.	5. Glass.	9. Wood.	13. Resin.
2. Flannel.	6. Cotton.	10. Metals.	14. Sulphur.
3. Ivory.	7. Silk.	11. Caoutchouc.	15. Gutta-percha.
4. Rock crystal.	8. The hand.	12. Sealing-wax.	16. Gun-cotton.

Positive and negative electricity are related to each other somewhat as heat and cold.

In a room where all objects have the same temperature, two bodies rubbed together become heated, in most cases unequally. The phenomena of heat would resemble those of electricity if the temperature of one of the bodies was raised and that of the other diminished. To carry out the analogy, if the two bodies had originally the temperature of the hand, one would grow cool and the other warm by friction. If left in contact, the bodies would become *un*heated again, as two electrified bodies become *un*electrified under similar conditions.

The following Laws of Electric Attraction and Repulsion have been determined :—

1. Electric charges of like signs repel each other; electric charges of opposite signs attract each other.

2. The force with which each of two charges attracts or repels the other, is directly proportional to the product of the two quantities of electricity, and inversely proportional to the square of the distance between them.

The Unit Quantity of Electricity is the quantity which will attract an equal quantity of opposite sign at a distance of 1 cm., with a force of one dyne (see page 90).

Suppose a unit quantity to be placed on a small sphere at A (Fig. 324), and an equal quantity on a sphere B, the distance between the centers of the spheres being one centimetre. The spheres would be pulled together with a force of one dyne. Two spheres at B would each attract A with the same force. If the two charges at B were on

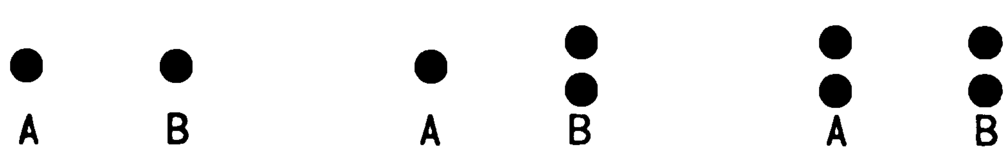


FIG. 324.—ILLUSTRATING ATTRACTION BETWEEN UNIT QUANTITIES OF ELECTRICITY.

one body, the combined attraction on A would be two dynes. A would also attract each of the two with a force of one dyne, and would

attract two units at B with a force of two dynes. Two units at A would each attract the two units at B with a force twice as great as that exerted by one unit. The attraction of two units at A upon two units at B would therefore be four dynes, which is in all these cases the product of the two quantities. Similarly, m units at A would attract m' units at B with a force of $m\,m'$ dynes.

By doubling the distance, the force becomes one fourth as great. At three times the distance, it is one ninth as great, etc. These two laws have been proved by experiment with very great precision.

The formula which represents these laws is $f = \frac{m\,m'}{d^2}$.

If $m = 5$, $m' = 3$, and $d = 20$ cm., then $f = \frac{5 \times 3}{400} = 0{\cdot}0375$ dyne.

Questions.—What is the derivation of the term Electricity? Can you discern any relation between electricity and heat? When were the phenomena of electricity first known? How are differences of temperature obliterated? How, electrical differences? Explain Potential. When the potential of bodies differs, what must take place? Explain the most noticeable property of an electrified body. What simple experiments can you suggest to illustrate it? What is ozone, and how is it produced? Describe and explain the sensation when the face is brought near an excited body.

State the law of electric Attraction and Repulsion. How may it be illustrated with suspended pith-balls? With swinging glass tubes and metal rods? Explain what is meant by a Conductor; by a Non-conductor; by positive and negative electricity. Suppose rods of glass, iron, sealing-wax, and copper, to be rubbed with a silk handkerchief; which will attract pieces of paper? The pieces of paper attracted by the electrified rod are repelled after they touch it. Why? To what extent is the relation between positive and negative electricity analogous to that between heat and cold? Define the unit quantity of electricity?

METHODS OF ELECTRIFICATION.

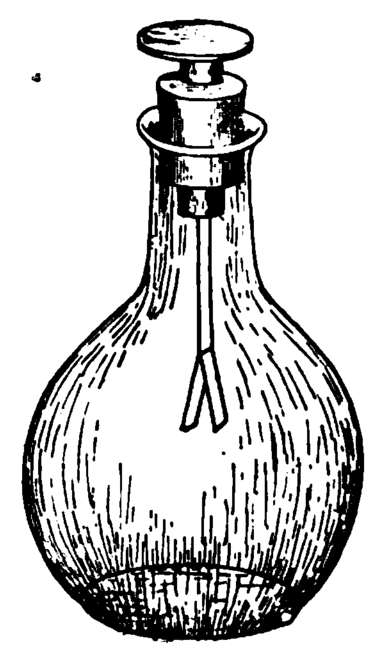


Fig. 325.—Gold-Leaf Electroscope.

The Electroscope.—The attractions and repulsions of electrified bodies are studied by means of the electroscope.

A very simple form of this instrument is shown in Fig. 325. It consists of a clean flask provided with a rubber stopper, through which passes a tube of hard rubber. Within this tube is a rod made of stiff copper wire. Attached to the lower end of the rod are two small gold leaves, which hang side by side. Soldered to the upper end of the rod is a brass or tin plate one or two

inches in diameter. A hole should be bored through this plate, into which a wire may be hooked.

The vessel must be closed while warm, dampness being fatal to all electrical experiments. Hence, such instruments are sometimes dried artificially by introducing calcium chloride, a compound which absorbs the moisture of the air.

Electrification by Contact.—Let a ball, A, supported on a stem of hard rubber or glass, be connected with the electroscope by a metallic wire (see Fig. 326). Excite a glass tube, a stick of sealing-wax, or a wooden ruler, by friction with flannel, silk, or a cat's skin, and bring it in contact with the ball. The gold leaves of the electroscope at once diverge, showing that they repel each other. Touch A with the hand and they collapse. The electrification has disappeared.

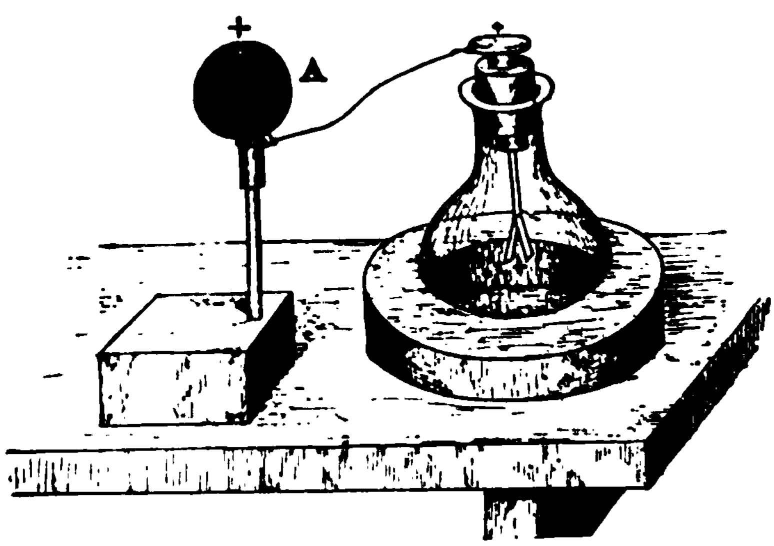


FIG. 326.—ILLUSTRATING ELECTRIFICATION BY CONTACT, AND THE CONDUCTING POWER OF DIFFERENT BODIES.

If the wire be replaced with a silk thread or a glass tube, no effect will be produced when A is touched with the excited body; but the leaves will diverge if the latter be brought in contact with the electroscope disk. This shows that a silk thread or glass rod does not conduct electricity. If the thread be wet, it behaves like a metal wire, but conducts more and more imperfectly as it dries.

Insulation.—A body like A, mounted wholly on non-conductors, is said to be *insulated.* A piece of metal held in the hand can not apparently be electrified, because the electricity is conducted away through the body.

Stroke the ball A with a cat's skin while it is connected with the electroscope by a conductor. Stand on an insulating stool, consisting of a dry pine board supported upon four tumblers or four small cakes of paraffine. Touch the

electrified knob or the electroscope. The leaves will fall somewhat together, but remain permanently deflected if you are well insulated.

If tumblers are used, they may have to be warmed, or perhaps exchanged for others, as some glass is not a good insulator. In touching the knob, you cause the charge on the knob and leaves to diffuse itself in part over your body.

Provide two insulating stools, and let a person standing on one stroke the hand of a companion on the other with a cat's skin. Both persons will become electrified, the first positively and the other negatively. This distribution of the charges can be tested by the electroscope. If the instrument has been charged by contact with an excited glass rod rubbed with silk, the hand of a positively charged person brought near the electroscope disk will cause the leaves to diverge more widely. To test the negative charge on the other person, the electroscope should be charged by contact with hard rubber or gutta-percha rubbed with flannel or a cat's skin. The leaves will again be repelled more widely. If the electroscope is electrified, a body oppositely charged, on being presented, will cause the leaves to fall together; but, as an unelectrified body would cause the leaves to behave in the same manner, the repulsion of the leaves is always the safe test.

Electrification by Induction.—Suppose two insulated balls, A and B, to be placed in contact with each other, as in Fig. 327. Rubber balls, covered with gold-leaf or tin-foil, or even two apples, will answer the purpose. If apples are used, they must be mounted on a rod, or a tube sealed at the end to keep out moisture, or they may be hung on silk cords.

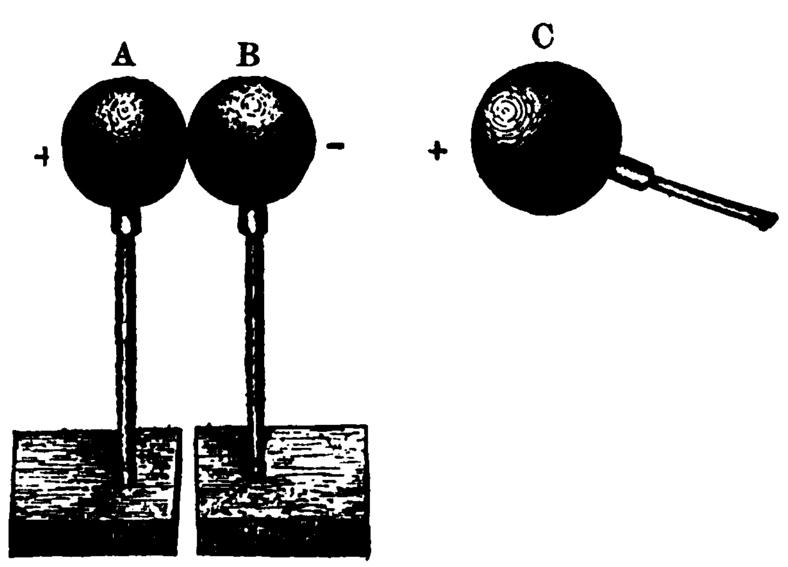


FIG. 327.—ILLUSTRATING ELECTRIFICATION BY INDUCTION.

Bring an electrified body, C, near one of the balls, as shown. Now move A away, while C remains in position. Both A and B will be found to be electrified. The opposite

electricity appears to have been attracted to the nearer ball, and the like electricity repelled to the more distant one. If the electricity of the *inducing* body C is reversed in sign, the charges on A and B will be reversed likewise.

When a body is thus electrified by means of another electrified body, without contact, it is said to be *electrified by induction.*

Discharge A and B by touching them, and again bring C to the position shown in Fig. 327. The two bodies are again charged. Next remove C, and afterward test A and B. They will be found neutral.

While the bodies are all in the position shown in Fig. 327, touch either A or B with the hand. A feeble spark will be felt. Remove the hand, and the two bodies A and B will seem neutral in the presence of C. If C is removed, the two bodies will be found charged with electricity the opposite of that on C. When the body was touched by the hand, the repelled electricity escaped to the ground, through the person of the experimenter. The attracted charge was held or bound by the opposite charge on C. When the body C was removed, the bound charge on A and B became a free charge. It would then go to the earth if received by the hand.

The Electroscope is best charged by Induction.—Bring an electrified body—a glass rod, for instance—near the instrument. The negative electricity will be attracted to the plate, and the positive electricity will be repelled to the leaves, which will diverge. Touch the plate, and the leaves will collapse as the repelled electricity upon them escapes. Now remove the inducing-rod. The leaves again diverge as the attracted electricity is diffused over them.

There remains a free charge on the electroscope leaves, having the opposite sign from that contained on the inducing body. If the inducing-rod be now brought up toward the electroscope, the leaves will again collapse. Any positively-charged body will produce the same effect; but a negatively-electrified body will cause the leaves to diverge more widely, as more electricity is repelled to the leaves.

The Electroph'orus is a device for the electrification of a body by induction. Into a shallow dish of metal pour

melted sealing-wax, making the surface of the layer as level as possible. To the center of a somewhat smaller metal disk, fasten a handle of glass. Avoid sharp edges on the disk.*

Stroke the sealing-wax with a cat's skin or a raccoon's tail, so as to electrify it negatively. Place the disk upon the excited wax, and its neutral electricity will at once be decomposed by induction, the lower surface being positively and the upper surface negatively electrified. Touch the disk with the finger, so that its negative electricity may be conducted away. Then lift the disk by the insulating handle, and it will be found sufficiently charged with positive electricity to yield a spark when the knuckle is presented. The spark will ignite gas from a Bunsen burner, if the burner is connected with the gas-pipe by a metal wire. These experiments may be repeated several times, in favorable weather, without freshly rubbing the wax.

FIG. 328. -THE ELECTROPHORUS.

Instead of touching the finger to the disk, as in Fig. 328, the point of a sewing-needle held in the hand may be brought near it.

QUESTIONS.—Describe the gold-leaf Electroscope. In what way is dampness excluded? How may it be charged by contact? How positively? How negatively? When is a body said to be insulated? Describe an insulating stool; an experiment by which two persons on insulating stools may be charged with positive and negative electricity. Why can you not depend on the collapse of the gold leaves in determining the electrical state of a body brought near the electroscope?

Explain fully electrification by Induction. How may you charge the electroscope by induction? If it is charged negatively and an insulated brass ball is brought near, what is the electrical condition of the ball when the leaves slightly collapse? When they slightly diverge? Suppose two insulated metal balls to be placed in contact, and a positively-electrified glass rod to be brought near one, and, while it is in position, remove the other. Then remove the glass rod. On

* Any tinner can furnish the requisites for a cheap electrophorus.

bringing the balls near to each other again, a spark will pass between them. Give the reason. Explain the action of the Electrophorus. Place a pith-ball on a metal plate provided with a glass handle; then place the plate on a cake of resin which has been rubbed with a cat's skin. When the plate is touched with the finger and then lifted by the handle, the pith-ball jumps off. Why? What must you do in order to get a succession of sparks from the electrophorus?

ELECTRICAL MACHINES AND CONDENSERS.

Electricity confined to the Surface.—No electricity exists on the inner surface of a conducting shell. In Fig. 329 an insulated cylinder of wire gauze is represented as electrified and as repelling the pith-balls hung on the outside. Those on the inside are not affected.

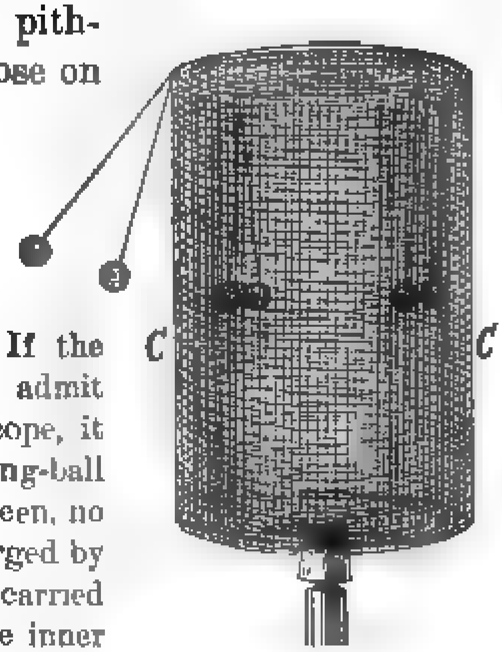


FIG. 329.—INSULATED CYLINDER OF WIRE GAUZE, WITH PITH-BALLS.

A metal ball hung on a silk cord, if brought in contact with the outside of the electrified wire screen, receives a charge, as is shown by its effect on the electroscope. If the wire screen is made large enough to admit an experimenter with the electroscope, it is found that, by bringing the testing-ball in contact with the inside of the screen, no charge is obtained. If the ball, charged by contact with the outer surface, is carried inside and placed in contact with the inner surface of the screen, its whole charge goes to the external surface.

Electricity may be attracted to the inner surface of a hollow ball by a charge upon an insulated body within the cavity (see Fig. 343). If the body makes contact inside the cavity, the charge escapes to the surface.

The principle explained above is practically applied in a variety of so-called *electrical machines*, contrivances for developing and collecting large quantities of *statical* electricity, or electricity produced by friction.

In the Induction-Machine is utilized the principle of electrification by induction.

One form is shown in Fig. 330. Here I I are *inductors*, supposed to be at different potentials. They have the form of hemi-cylindrical shells. The hollow metal balls *a* and *a′*, called *carriers*, are mounted on the ends of radial insulating

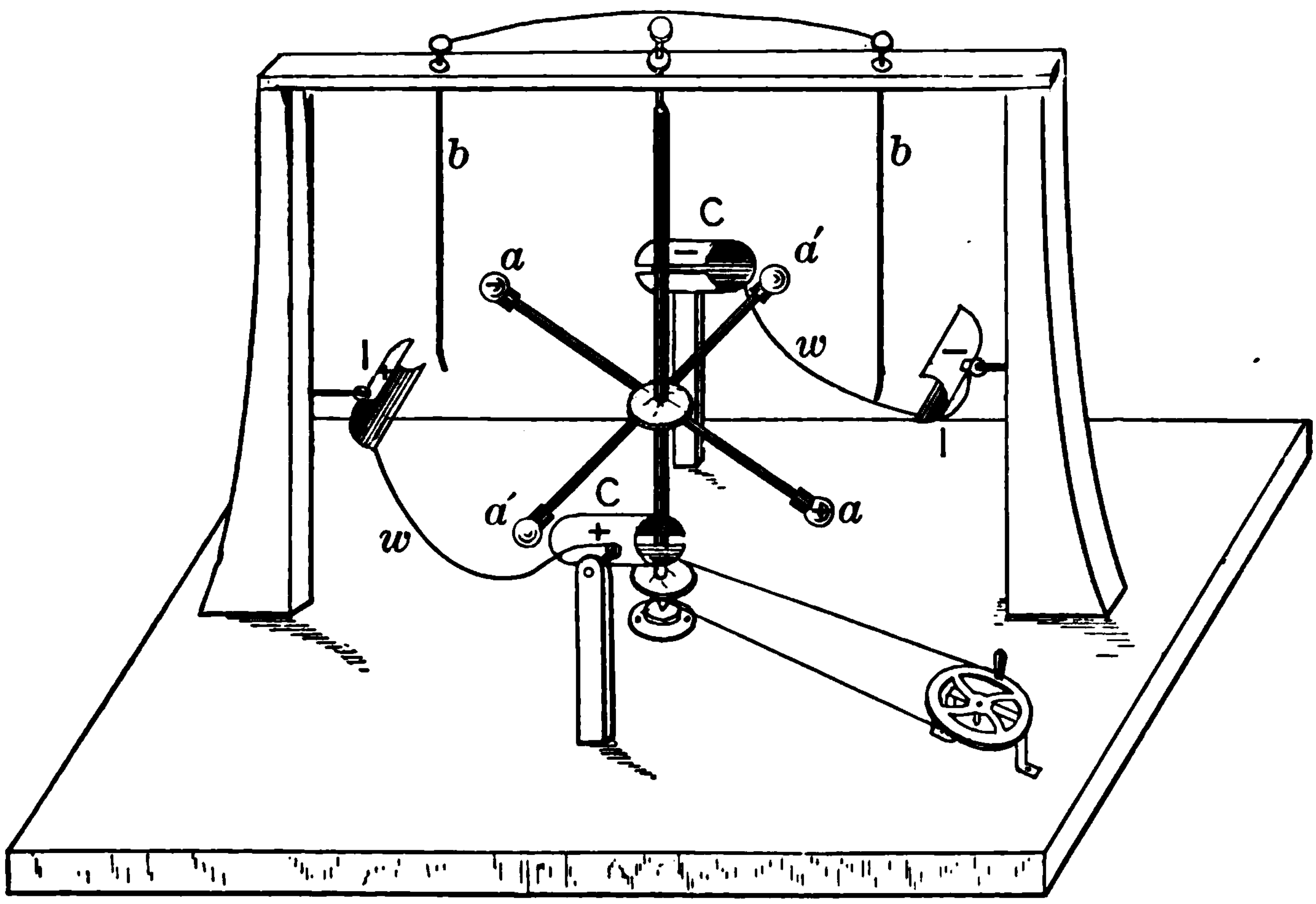


FIG. 330.—INDUCTION ELECTRIC MACHINE.

rods, and revolve around a vertical axis. As the balls sweep through the concave inductors they are momentarily placed in metallic contact with one another by means of springs mounted on rods, *b b*, which are connected by a wire. The repelled charges of opposite sign cancel each other by being added together on these rods. As the carriers move on to the positions *a a*, each will have a free charge, opposite in sign from that on the inductor which it has just left.

The balls, *a a*, next pass inside of the *collectors*, C C, where they touch a metal spring, by means of which their charges are wholly carried to the external surfaces of C C. The carriers, when in the position *a′ a′*, are therefore neutral, and the same operation is repeated. Each collector is connected by means of a wire, *w*, with the inductor toward which the carrier moves.

There will always be such a difference of potential between the two sets of conductors in this machine that, when the carriers are turned, the electrification will begin and will increase until the leakage in a second equals the amount added. If, several hours after you have brushed your clothing, you should stand nearer to one side of the machine than to the other, this will be enough to cause it to excite when turned. When the machine is to be used for producing sparks, each rod of the universal discharger (see page 460) must be connected with one of the wires, *w w*.

In Sir William Thomson's Water-dropping Electric Machine, two jets of water, J, from any common source, H, fall through two hollow cylindrical inductors, I (see Fig. 331). The jets are controlled by screw-clamps, so that they break into

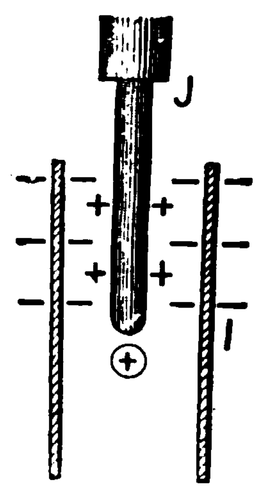


FIG. 332.

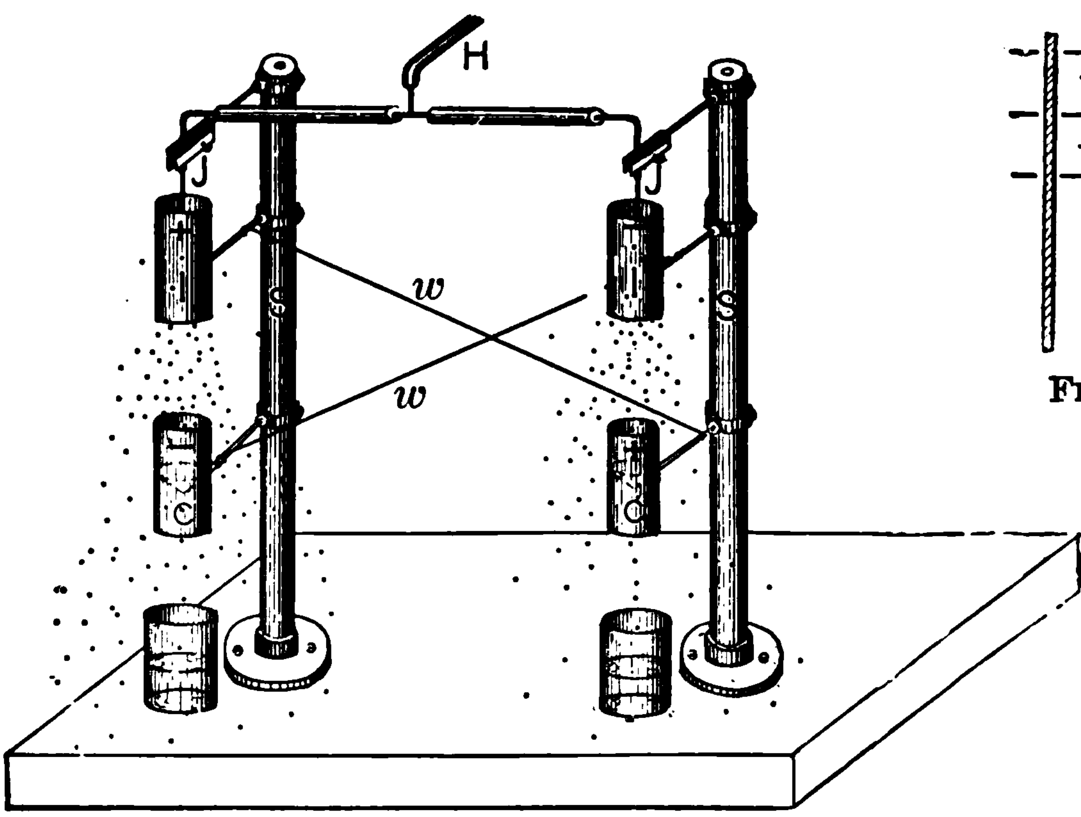


FIG. 331.—WATER-DROPPING INDUCTION-MACHINE.

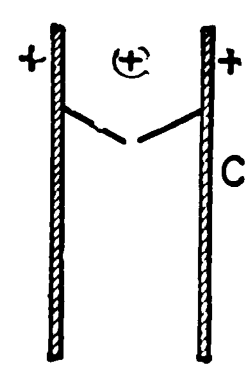


FIG. 333.

drops half-way through the inductors, as shown in vertical section, Fig. 332.

There is always sufficient difference of potential between the two inductors to start the machine when the water begins to drop. In the inductor which is negative with respect to the other, the jet forms a conductor, the nearest end of which is positively electrified by induction. The negative charge is repelled up the jet, and the drops fall away posi-

tively electrified into a funnel on the inside of the collector below. Here they lose their whole charge, which goes to the external surface. The positively-charged collector is connected with the inductor on the other support by means of a wire, *w*. This inductor acts precisely like its companion, a change of sign only being required for the explanation.

The drops of water constitute the carriers. On each side, the drops are falling away from an inductor which attracts them, and toward a collector which repels them. They also repel one another; hence a large part of them fall outside of the collectors. A difference of potential of about 7,000 volts (see page 493) can easily be maintained by this device, as long as the water-supply is kept up.

The supporting columns may be made from heavy glass tubing. The inductors should be about an inch and a half in diameter, and three or four inches in length. The whole apparatus can be made by the pupil with the aid of a tinner, and affords a most instructive illustration of many of the phenomena of electricity.

Action of Points.—If an insulated cylinder of brass, having rounded extremities, be connected with an electric machine, and a test-ball be then applied at different parts of the surface of the cylinder, the ball will be found most strongly charged when applied at the ends. It will then affect most forcibly the gold leaves of the electroscope.

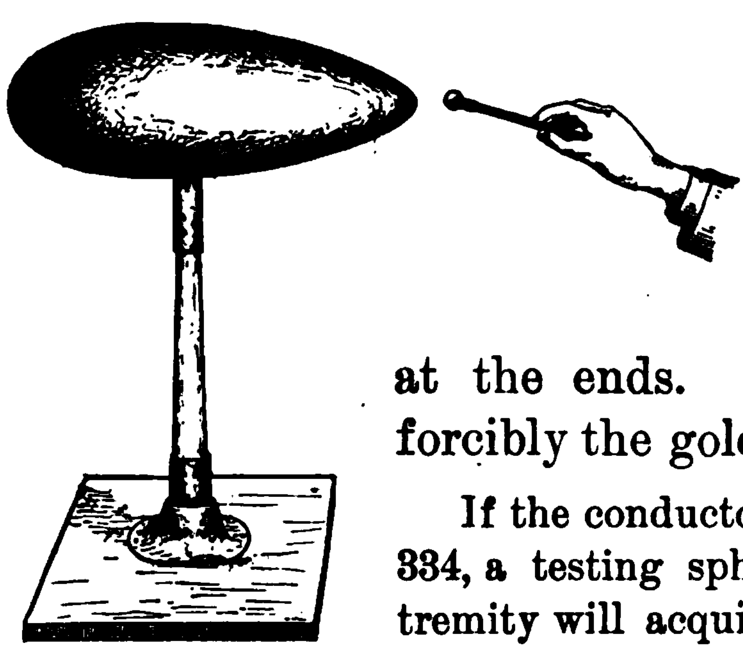


FIG. 334.

If the conductor have the form shown in Fig. 334, a testing sphere applied to the pointed extremity will acquire a greater charge than at the rounded end, the least charge being acquired when contact is made at the side. The *density* of the charge is said to be greatest at the ends. If the electrified body terminates in a sharp point, as in Figs. 335 and 336, the density is so great that the electricity escapes from the point very rapidly and the body becomes neutral. In the dark, the point appears tipped with a luminous glow called a *brush.*

Should the flame of a candle be held in front of the point, it will be blown aside, because the particles of air in the immediate vicinity of the point, having become electrified by contact, are repelled by the highly charged point with such velocity as to drive back the flame in turn.

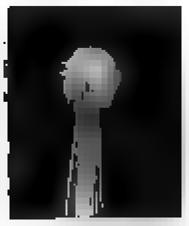


FIG. 335.—ELECTRIC BRUSH.

The mutual repulsion between points free to move and the electrified air which flows from them, is illustrated by the electric whirl or flier, consisting of metallic wires branching out from a common center, and with pointed ends bent in the same direction. If the whirl is balanced on a rod attached to the conductor of an electric machine in action, it will revolve in a direction *opposite* to that in which the bent wires point. Why? When the room is darkened, the points become luminous, and a circle of fire seems to be formed.

The faint glow known as St. Elmo's fire, sometimes seen tipping the extremities of masts, bayonets, and even the ears of horses, particularly during thunder-storms, is electricity slowly discharging itself from or into pointed bodies.

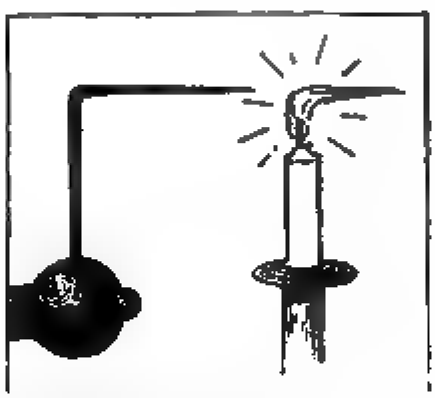


FIG. 336.—CANDLE-FLAME REPELLED BY ELECTRICITY FROM POINTS.


FIG. 337.—ELECTRIC WHIRL.

This action of points is utilized in some forms of electrical machines, now to be described. The conductors of all electrical machines terminate in rounded ends or edges, in order to avoid leakage. They should be kept free from dust, as brush discharges are likely to stream even from dust-particles.

The Toepler-Holtz Machine, a celebrated generator of electricity both for medical purposes and physical use see No. 3, page 435), is really a combination of two in- tion-mach that described on page 447. On the

back of a stationary glass plate (Fig. 338) are two cards, X X, which act as inductors; and on a smaller revolving glass plate, in front of the former, are pasted a series of carriers, *a a'*, made of tin-foil, each of which has in its center a metal button or stud designed to serve as a contact. As the

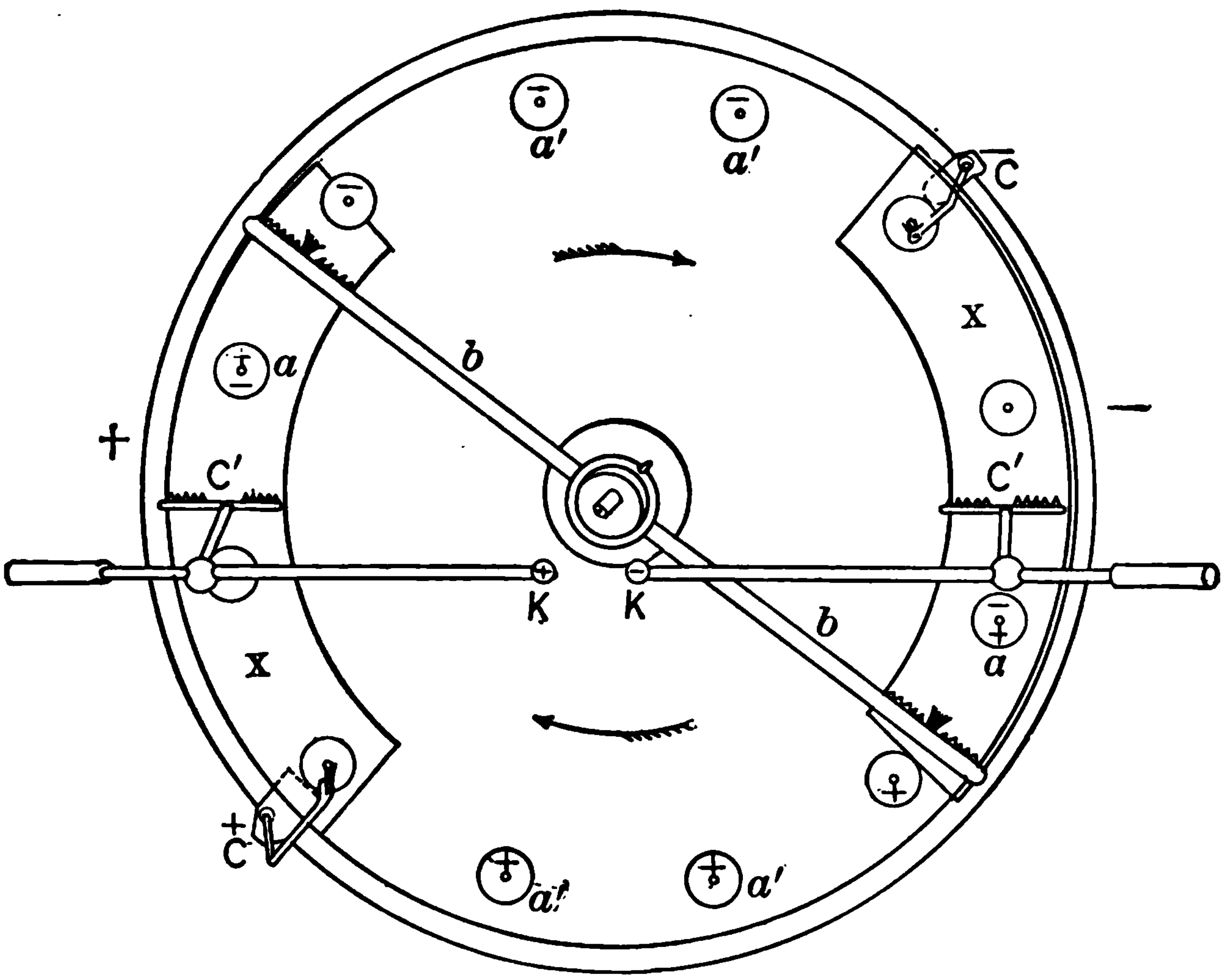


FIG. 338.—PRINCIPLE OF THE TOEPLER-HOLTZ MACHINE.

carriers are about to leave the inductors, the two on the same diameter are touched by flexible metal springs or wire brushes fixed to the stationary diagonal rod *b*, which crosses the moving plate. The repelled charges on the carriers are thereby simultaneously removed, exactly as is done by the rods *b b* in Fig. 330.

Passing to the opposite inductor, each carrier touches a second metal brush in contact with that inductor through rods C C. The bound charge which each carrier held at the previous contact with the diagonal rod *b*, while in front of the other inductor, is now in part communicated to the inductor having a like charge, through the collectors C C. The function of these carriers is to restore the charges which leak away from the two inductor-cards, the operation being ex-

actly like that shown in Fig. 330. One of the cards is thus rapidly replenished with positive, the other with negative, electricity.

As the inductors become charged, they act inductively on the revolving plate, electricity of the like sign being repelled to the surface farthest from the card inductor. The *combs* C′ are also acted upon inductively, and electricity of the opposite sign from that on the card is attracted, and streams from the points of the combs in a brush discharge upon the plate. When, for instance, any part of the glass in its revolution arrives at the comb C′ on the right, the negatively-charged glass around the collector is rendered neutral by an attracted brush discharge from the comb, which leaves a repelled or free negative charge on the conductor. These conductors terminate in knobs, K K, between which a discharge of sparks is thus kept up while the glass plate is in revolution. In the second half of a revolution, the operations are all repeated, the signs of the charges being reversed.

The action of the Toepler-Holtz machine is the same as that of the electrophorus.

The Friction Electric Machine, the oldest form, but far inferior to the modern induction-machines as a producer of electricity, is a simple contrivance for rubbing glass and silk or leather together, and collecting the electricity generated. One form consists of a circular plate of glass, A (see Fig. 339), which may be revolved between cushions, D, coated with an amalgam (usually composed of zinc, tin, and mercury, mixed with grease). When the plate is revolved, the lower part becomes positively electrified. The electricity is collected by the comb F and carried to the prime conductor P, which is mounted on a glass column or fixed, insulated, to the stand of the machine. The clamp at the same time receives an equal negative charge, which is communicated to a second insulated conductor, N. The silk apron, S, in a measure prevents leakage.

Connect P and N by a wire. They will both remain neutral, or at the same potential as the earth. Insulate them from the earth and from each other, and N will become negatively charged, P positively. In other words, the potential of N sinks below, while the potential of P rises above, that of the earth. The difference of potential is dependent on the materials rubbed together. A spark can be drawn from either conductor by any person standing on the floor.

Connect either P or N with a gas or water pipe, or a lightning-rod having a good earth connection. Even a chain lying on the floor will serve the purpose. This is called "grounding" the conductor. Much longer sparks can now be drawn from the other insulated conductor, but none can be obtained from the grounded conductor. If N has

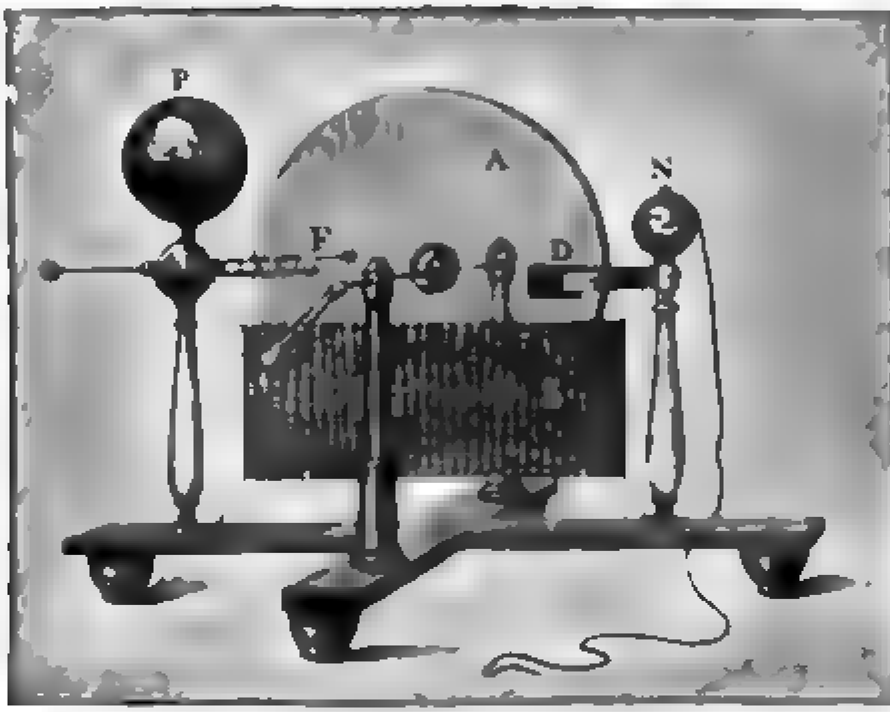


FIG. [illegible].—FRICTION ELECTRICAL MACHINE.

been grounded, its potential has been raised to that of the earth; but the potential of the positive conductor has been similarly raised, since the difference in potential has not been changed. The difference of potential between the earth and the insulated conductor is therefore increased. Sparks of the same length may be drawn from each conductor if both are insulated, and a person, standing on an insulating stool, touch either and present his knuckle to the other.

A person on an insulating stool, having once touched the conductor, receiving a spark as he does so, may again touch it without receiving a spark. He is already charged to the potential of the conductor, and the electricity can not leak away. A person on the floor may draw a spark from him when thus charged.

NOTE.—In another form of the friction-machine a glass cylinder is used instead of a circular plate. Cylinders of glass, amalgam, etc., may be purchased at slight cost from instrument-dealers, and the pupil may easily construct a simple friction-machine for himself.

Electrical Condensers, or accumulators, assume a variety of forms, according to the uses for which they are designed. A common condenser is the Leyden (*li'den*) jar,* which may be used with all the forms of electrical machines so far described.

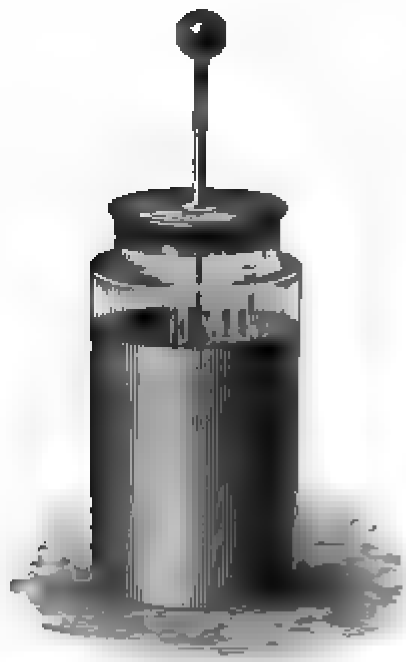


FIG. 340.—THE LEYDEN-JAR.

The Leyden-jar is merely a glass vessel coated within and without, for about two thirds of its height, with tin-foil, put on with flour-paste. Through a cork or wooden cover closing the mouth, passes a metal rod, which terminates above in a ball (why?), and from which a chain hangs in contact with the inner lining of the jar.

If two such jars are connected with the Holtz machine, as shown in Fig. 341, the character of the discharge between the two terminals

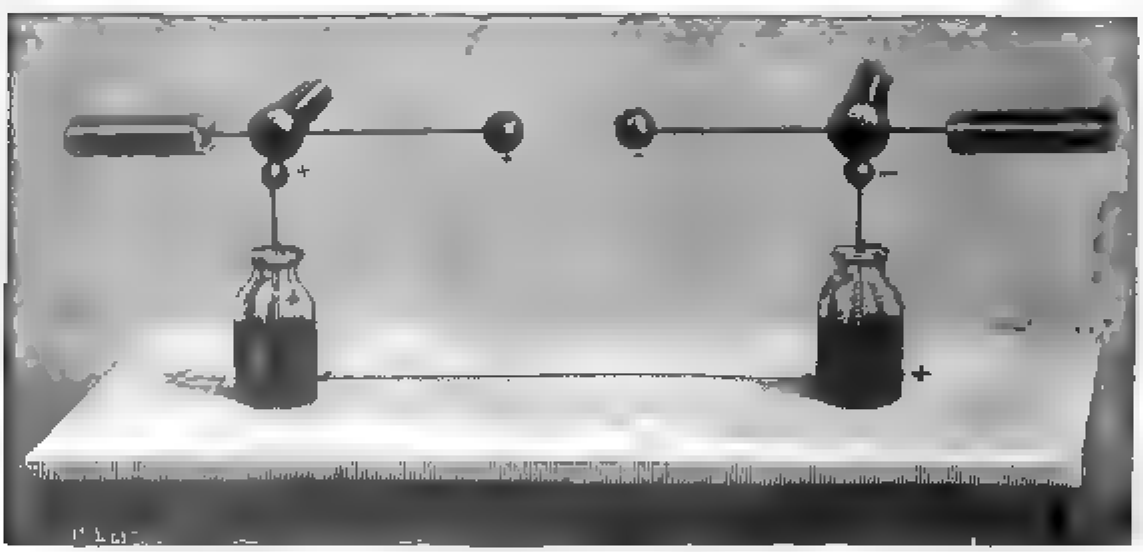


FIG. 341.—LEYDEN-JARS IN CONTACT WITH TOEPLER-HOLTZ MACHINE.

changes entirely. Instead of a continuous brush discharge, accompanied by a rustling and crackling sound, the discharge comes at inter-

* So called because first used at Leyden, Holland.

vals, the length of which increases with the width of the gap between the knobs, and with the size or number of the jars. The electricity appears to accumulate until the jars are charged, and then breaks through the air with a sound like the crack of a whip. Immediately after the spark has passed, the whole machine is virtually discharged, as may be seen by suddenly stopping the revolving plates when the spark passes.

One or more jars may be used with the Holtz machine, by connecting all their inside coatings with one another and with one side of the machine, while the outside coatings are connected with the other. The connecting wires should have a globule of solder upon their ends, in order to prevent leakage. The jars should all be insulated.

Action of the Leyden-jar.—If two metal sheets, about two feet in diameter, are hung up in parallel on silk cords, they will act as a condenser. Two sheets of zinc, such as are put under stoves, will answer very well if the edges and corners are smoothed. It is necessary to suspend each piece on two cords, in order to keep them in position. The sheets may be connected by means of a fine wire with the conductors of the Holtz machine, which should already have the two Leyden-jars belonging to it attached.

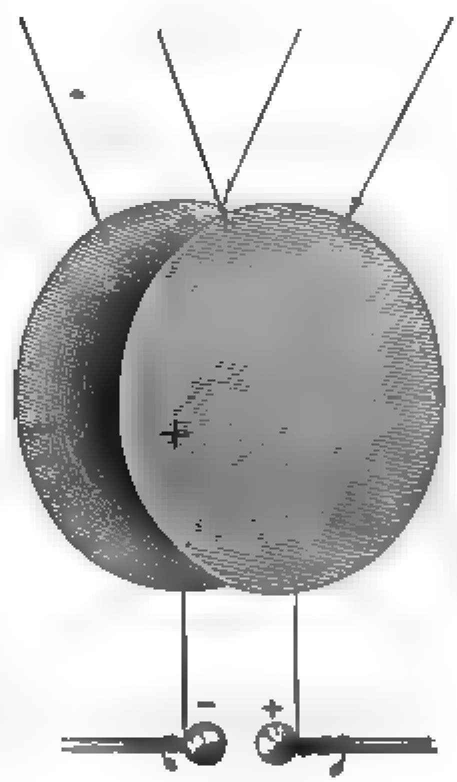


FIG. 342.—ILLUSTRATING ACTION OF LEYDEN-JAR.

It will be found that, with the same speed of rotation, the sparks will come less frequently. The metal plates will be attracted together unless held apart by silk cords or other insulators. If the distance between the plates is doubled, the sparks will pass twice as rapidly between the knobs of the Holtz machine. Increasing the size of the plates, or placing them nearer together, increases the interval between the sparks. It is also said to increase the capacity of the condenser. The greater the capacity of the condenser the longer the time required for it to become

charged with electricity, so that a spark will break across between the knobs when placed a fixed distance apart.

The reason for the greater capacity of one of the plates, when near the other, is due to the attraction between the two charges of opposite sign upon the plates. This attraction is shown by the motion of the plates toward each other.

Disconnect the plates from the machine, and touch them alternately. Only a feeble charge will pass to the hand at contact. After many such alternate contacts, if the plates are touched simultaneously, a smart shock will be felt. When only one plate is connected with the ground through the body, the electricity on it can not escape, because of the attraction of the electricity on the other plate.

Another Form of Condenser, for experimental purposes, is shown in Fig. 343. It is simply a hollow spherical conductor, with an opening cut in the top. This opening is closed by a cover fitted with a glass handle, and is large enough to admit a gilded rubber or hollow metal ball, which is suspended from a hook in the cover by a fiber of silk. An opening in the side will serve to admit a copper wire covered with rubber, or a knitting-needle coated with sealing-wax, to be used as a charger.

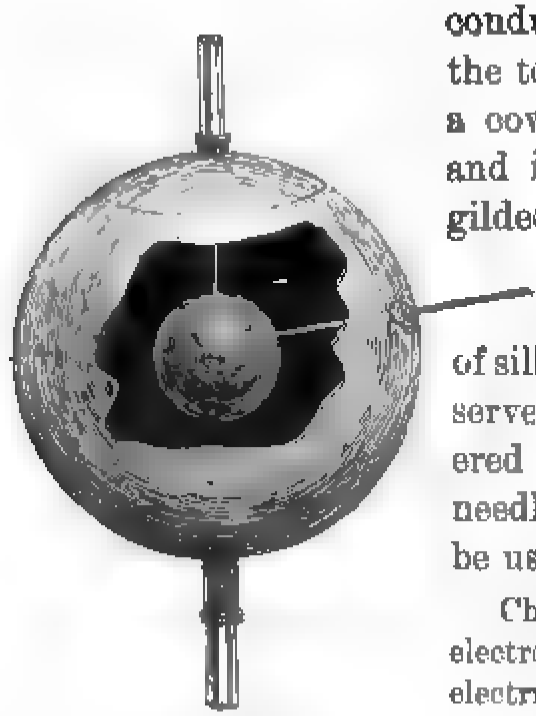


FIG. 343.—SPHERICAL CONDUCTOR, WITH INCLOSED ELECTRIFIED BALL.

Charge the inner ball by means of the electrophorus or either conductor of the electrical machine, and remove the charging-wire. Suppose this charge to be positive. Then a negative charge will be attracted to the inside of the outer shell, while an equal positive charge will be repelled to the outer surface. Lift out the inner sphere without touching the outer shell. The latter will be found unelectrified, showing that the two charges are equal. Replace the charged sphere. The outer sphere will now appear electrified again, and will affect the gold leaves of the electroscope if the testing-sphere connected with it be brought near.

Next touch the outer sphere with the hand. The repelled charge

will escape, but the two bound charges will still remain. They exert equal and opposite effects on the electroscope. If the silk fiber now be broken, so as to make contact within, the whole system will instantly become neutral. This proves that the induced charge on the outer sphere is equal to the inducing charge on the inner sphere.

If the spheres are neutral, and a charge is communicated to the outer shell, no charge will be induced on the inner shell. The whole charge will remain on the outer surface of the outer shell.

Act inductively upon the two spheres, one of which incloses the other, as was done on the bodies A and B, in Fig. 327. The attracted electricity will be found on the outer surface of the outer shell, nearest the inducing body, while the repelled charge will be on the side farthest from the inducing body, and also on the outer surface. No electricity can be found on the inner ball, or anywhere in the interior cavity.

FIG. 344.—WIRE CYLINDER INCLOSING ELECTROSCOPE.

Screening Effect of a Metallic Shell.—Any space completely surrounded by a metallic or conducting shell is

shielded from all electrical influence from without. This is best shown by setting a screen made of common wire gauze over the electroscope, the latter resting upon a metal sheet. Sparks from the electric machine may be sent through the wire netting, and electrified bodies may be moved about outside of the screen, without in the least degree affecting the gold leaves. If the screen and electroscope rest upon the poorly-conducting table instead of the metal sheet, the leaves are at once affected. A powder-house inclosed wholly in sheet-iron, the floor included, would be safe against lightning.

Cause for the Increased Capacity of Condensers.—The small sphere of Fig. 343 has a less capacity in the open air than when surrounded by the concentric shell, because of the attraction of the opposite electricity induced on the outer shell. The attracting charges seem to bind each other. The same action takes place on the coats of a Leyden-jar. A sphere within a room has a greater capacity than when in the open air. The walls of the room act as the outer coating of the condenser.

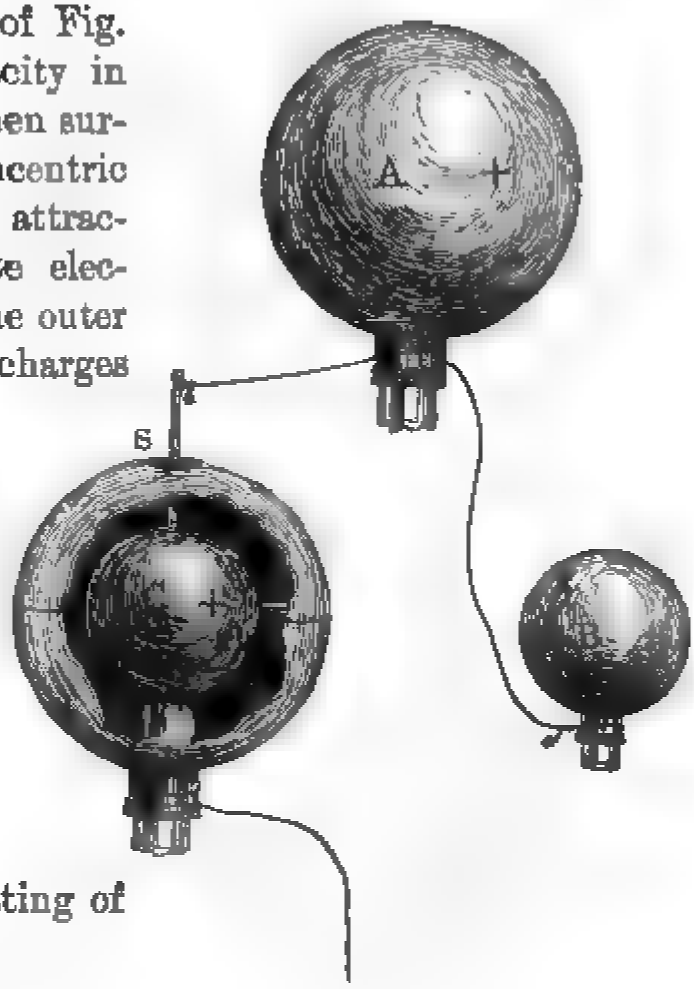


FIG. 345.—INCREASE OF CAPACITY BY METALLIC SHELL.

The Capacity of a Body for heat is measured by the amount of heat required to raise its temperature one degree. It will be noted that the capacity is not measured

by the amount of heat the body will hold. Any amount of heat may be added to it, and the temperature will rise with the amount added.

The capacity of a body for electricity is measured by the amount of electricity required to raise its potential by unity.

Suppose electricity to be added to a body, A (Fig. 345), until its potential is raised to unity, that of the earth being always assumed to be zero. Now, suppose electricity added also to B until no spark would pass if A and B were momentarily connected by a fine insulated wire. Then A and B are said to be at the same potential. Suppose a body, C, equal to B in size but surrounded by a grounded metallic shell, S. is also charged until no spark passes when C and A are similarly connected. The bodies A, B, and C, have then all the same potential.

It is found that it takes more electricity to charge C than B. The effect of the shell has been to increase the capacity of the inner body. The capacity increases as the radial distance between ball and shell diminishes.

A toy balloon, coated with soot or graphite powder to make it conducting, may be loaded to equilibrium. If electrified, it will then rise. The electrical forces make the balloon slightly larger.

Questions.—Prove that electricity is confined to the outer surface of bodies. How may it be attracted to the inner surface of a hollow ball? What are Electric Machines? Describe an induction-machine in which the inductors are semi-cylindrical shells; Sir William Thomson's water-dropping machine. What can you say of the action of points? Define an electric brush. What happens when the flame of a candle is brought near a charged point? Explain St. Elmo's fire. How is this action of points utilized in electric machines? State the effect of smooth and rough surfaces on the escape of electricity.

Describe minutely the Toepler-Holtz Machine, referring to the illustration on page 451. Compare its action with that of the electrophorus. Describe the plate electric machine. In this machine the conductor is of rounded shape at all parts except where it comes nearest to the glass plate. Here it is provided with sharp projecting points. Explain this. Why will not a plate machine work well in damp weather? If a silver tea-pot be insulated and electrified, and you touch it in different places with a penny fastened to the end of a stick of sealing-wax, what part of the pot will give the greatest and what part the least quantity of electricity to the penny? How may you decide with the help of the electroscope?

What are Electrical Condensers? Describe a Leyden-jar, and the method of charging it by means of electric machines. Illustrate its action in the case of two sheets of zinc. Prove that the induced charge on an outer spherical con

ductor is equal to the inducing charge on an inner sphere. Explain the screening effect of a metallic shell or wire cylinder. Under what conditions would a powder-house be safe from lightning? What is meant by the capacity of a body for heat? For electricity?

THE ELECTRICAL DISCHARGE AND ITS EFFECTS.

Dischargers.—In discharging several Leyden-jars connected so as to act as one, it is necessary to use some form of discharger to avoid a shock, for even a slight shock might

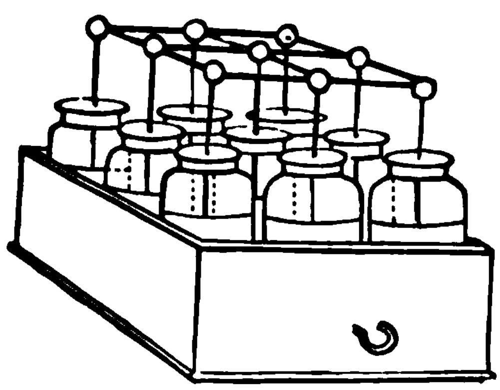


FIG. 346.—BATTERY OF LEYDEN-JARS IN BOX LINED WITH TIN-FOIL.

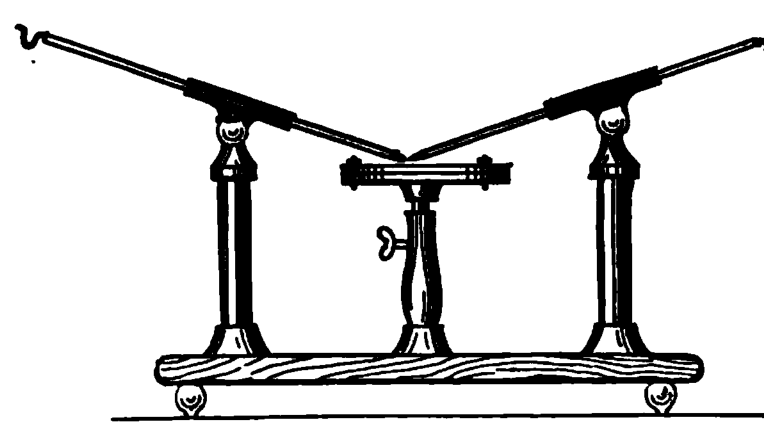


FIG. 347.—UNIVERSAL DISCHARGER.

cause the death of a person affected with heart-disease.* Hand-dischargers are jointed conductors provided with glass or rubber handles (see No. 4, page 435). In the universal discharger (Fig. 347), the two conductors are supported on glass columns, to which they are hinged so that

* An interesting incident is related in connection with the experiments that led to the invention of the Leyden-jar. Prof. Van Musschenbroek (*mus'ken-brŏŏk*), of Leyden, observing that excited bodies soon lose their electricity in the air, determined to see whether he could not collect and insulate the electricity in a vessel of non-conducting glass, so that it might be kept locked up, as it were, ready for use. Accordingly, he introduced a wire from the conductor of an electric machine into a bottle filled with water. After the machine had been working some time, an attendant, holding the bottle in one hand, attempted to withdraw the wire with the other, when he, of course, received a shock, so unexpected and so unlike anything he had ever felt before, that it filled him with consternation. Van Musschenbroek himself subsequently took a similar shock, which he described in a letter. He says that he felt himself struck in his arms, shoulders, and breast, so that he lost his breath, and it was two days before he recovered from the effects of the blow and the fright. He would not, he adds, take a second shock for the whole kingdom of France. The shock of a powerful battery will kill a man and fell an ox; even moderate discharges prove fatal to birds and the smaller animals.

they may be placed in any position. A glass table between serves to support and insulate the body upon which experiment is to be made.

Effects of the Electric Spark.—The effect of the discharge from any given jar or combination of jars depends on the nature of the body through which the discharge takes place. Bad conductors are shattered. Good conductors, if sufficiently large, are not apparently affected. All bodies are heated, so that a fine metal wire may become warm or may even fuse.

Place a piece of dry sole-leather or a book between the knobs of the Holtz machine, and a hole may be made in it by the spark. Thin glass may be pierced in a similar way. This shows that the medium

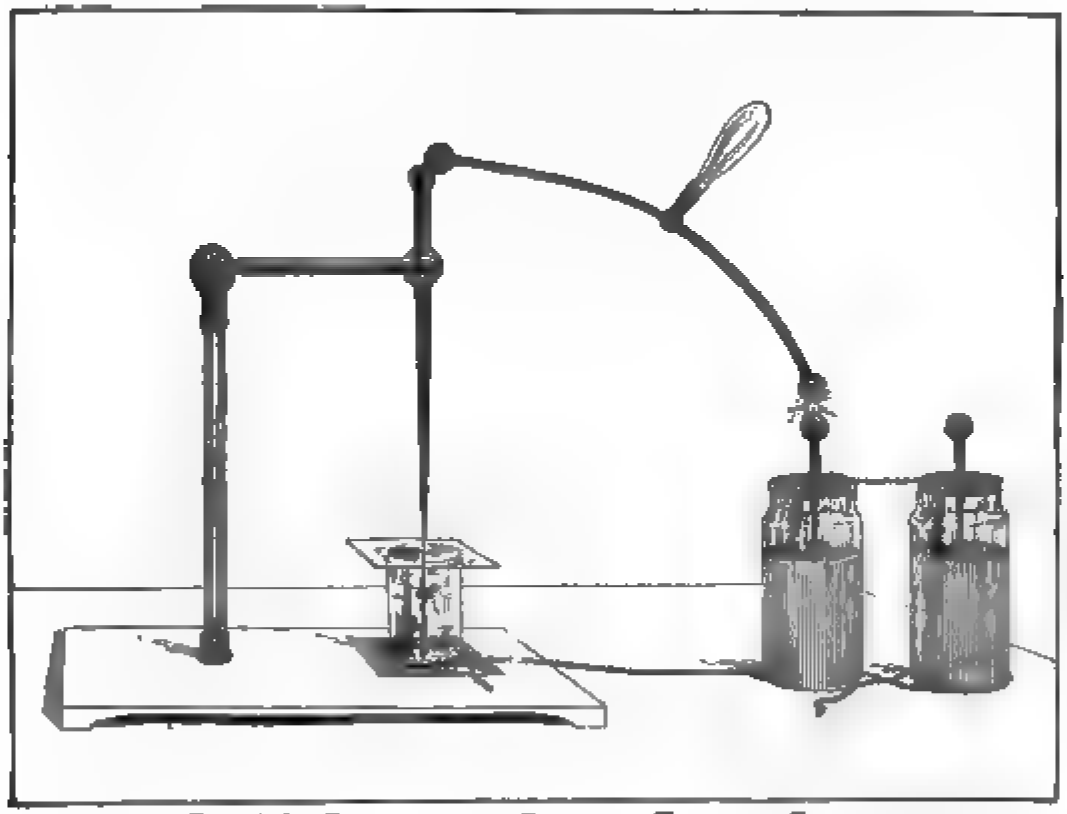


FIG. 348.—PUNCTURE OF GLASS BY ELECTRIC SPARK.

between the knobs is in a condition of *stress*, which may produce a rupture of the intervening body. Some idea of the force exerted may be obtained by pushing a punch through the leather or book.

If you desire to pierce a thin plate of glass, you may support it on a tumbler, as shown in Fig. 348. Bore a hole through the bottom of the

tumbler with the freshly broken end of a round file, moistened with a paste made of camphor-gum and spirits of turpentine. Let the tumbler rest on a sheet of tin-foil, in contact with a metal rod which passes up through it and ends in a sharp point in contact with the glass. Support an insulated rod above, terminating in a point exactly on the opposite side of the glass, which should be washed clean with soap and dried before a fire. A little oil may be poured on its upper face to keep moisture away. For a single jar, the glass must be very thin. If the spark passes around the glass, it is useless to repeat the experiment with the same plate. Plates of glass 2½ inches thick have been pierced by sparks from a powerful induction-coil (see page 518).

The Discharge in Rarefied Gases.—In the Geissler tube, platinum wires are sealed through the extremities into chambers, which communicate with each other through a tube of glass bent into various fanciful shapes. A spark passing from one wire to the other must traverse this bent tube. If the gas within is at atmospheric pressure, the spark will pass around the entire tube rather than through it. If the gas is pumped out, electricity will begin to flash through the tube when the terminal wires are in connection with the knobs of the Holtz machine. As the exhaustion proceeds, the electricity will finally pass in a continuous, flickering, noiseless discharge, revealed by a beautiful glow of light when the experiment is made in a dark room.

If the exhaustion is made more complete, the discharge is less brilliant, and finally will cease altogether. In the highest attainable vacuum, no spark will pass. At a certain pressure the discharge takes place most easily; the insulating power of the air is least. The tubes are sealed at this pressure. A nearly perfect vacuum thus implies high insulation; a partial vacuum is a good conductor.

The Discharge in Air—Lightning.—When the terminals of the Holtz machine have Leyden-jars attached, the electricity accumulates in the jars, and the electrical stress between the knobs increases, until finally the air ruptures, as does the glass plate. Against the pressure of the atmosphere, a long rarefaction similar to that of the Geissler tube forms between the knobs, through which the whole charge

of the jars passes. This is why the jars and machine are almost wholly discharged just after the spark has passed. It is as if the knobs had been momentarily connected by a fairly good conductor.

Along the line of the discharge, the air-particles are thrown into a state of intense vibration—they become extremely hot. They also give off a light, which yields a spectrum characteristic of the gas as well as of the terminals between which the spark passes. This shows that some of the metal composing the terminals is vaporized.

The pressure of the atmosphere quickly closes the rarefaction with a sound, which in large sparks like lightning is called a crash. The slight discharge of a Leyden-jar sounds like the crack of a whip, which is also due to the closing up of a hole in the air.

The Lightning-Flash.—The thunder-cloud and the earth constitute a huge condenser. The cloud is usually positively charged, and the opposite or negative electricity

FIG. 349.—LIGHTNING-FLASHES, FROM INSTANTANEOUS PHOTOGRAPHS.

is induced upon the surface of the earth. If the charges accumulate sufficiently, a spark will pass in a flash of lightning, illustrated in the accompanying photographs. It will be seen that the path of lightning is not zigzag in shape, as popularly supposed. In one of the pictures is apparent the beautiful branching effect often secured on sensitive plates.

Protection against Lightning.—There can be no doubt of the value of a properly constructed lightning-rod. Before the ships of the English navy were armed with con-

ductors, frightful disasters from lightning were not uncommon. They ceased with the introduction of the copper strips which Sir W. Snow Harris designed for attachment to the masts. The lightning-rod is intended to create a line of least resistance, along which the discharge must take place without damage.

Lightning-rods should rise in the air as high as chimneys, for otherwise the soot of the chimneys may lead the discharge into the house. The rods should not usually be higher than the highest points to be protected, as it is better not to attract the lightning, but to have it strike away from the house entirely. The region protected by a rod is approximately a cone, whose height is the rod and whose base has a radius equal to the height of the rod.

A lightning-rod should be without joints; or if jointed, the lengths should lap several inches and be tightly wound with copper wire. The rod should extend into the ground until earth is reached which is *always moist.* It is well to dig a hole several feet deep, and fill around the rod with powdered coke or charcoal. Two ground connections at opposite ends of the building are much better than one.

Thunder.—One end of the path of a lightning-stroke may sometimes be as much as two miles farther from the ear than the other. The passage of the discharge is practically instantaneous; but as sound travels only at the rate of eleven hundred feet a second, the duration of this thunder will be over nine seconds.

The path of the discharge is sometimes through air which is not acoustically homogeneous. The sound from some parts of the path is so refracted, reflected, or quenched by interference, that the thunder is barely heard for a second or more; then it bursts into a roar as sound from other parts of the path reaches the ear without meeting such obstruction. The roar may at this time also be re-enforced by sound from nearer points of the path, which has been reflected to the ear after having traversed an indirect route. The effect is not unlike the rumble of a distant railway-train

passing through cuts, tunnels, or groves of trees, and then out into an open stretch of track.

Duration of Lightning-Flashes.—We have shown that the duration of a lightning-flash is about the hundred-thousandth part of a second. It seems to be longer than this, because of the persistence of sensations on the retina. Falling rain-drops at night, when illuminated by lightning, seem to be stationary in the air. They do not appreciably move; even the most rapidly rotating bodies appear to be perfectly still while illuminated.

A jet of water will show similar results when illuminated by the spark of a Leyden-jar. In a dimly lighted room, the carriers on the Toepler-Holtz machine show as a hazy ring upon the rapidly revolving plate. When the spark passes between the knobs, they seem sharply defined and stationary. Similar experiments may be made with Newton's disk of colored sectors, or the spokes of a revolving wheel.

The Aurora is a luminous appearance believed to be of electrical origin. While it is not yet fully understood, all observations point to the conclusion that it may be referred to electrical discharge in the upper and thinner portions of the atmosphere.

Magnetizing Effect of the Spark.—It was early noticed by mariners that a lightning discharge often deranges or reverses the magnetism of the compass-needle, so that the end previously pointing north would point south.

The same effect can be produced with the comparatively feeble charge of a Leyden-jar.

Let the spark be led around a coil of metal wire having an unmagnetized steel knitting-needle in its axis. The wire coil must have an insulating coating, in order to keep the spark from breaking across from one turn to the next, and it is better to surround the steel with a glass tube to prevent the possibility of the sparks passing to it.

If the + charge of a jar is led around the steel in the direction shown in Fig. 350, the left-hand end of the steel will become a north pole and the right-hand end a south pole. The steel has become a magnet.

If you stand facing the end which has become a south pole, you will notice that the + charge has passed around the steel in the same direction as the hands of a clock revolve. This rule is always true.

These experiments will succeed best if the conductor wrapping around the outer coating of the jar is a wet string, which offers great resistance to the passage of the spark. When the circuit is all composed of good conductors like copper wire, the discharge of the jar is oscillatory. The electrifications of the coatings reverse thousands of times during the short interval of the discharge. Each reversal involves a partial reversal of the polarity of the steel wire, and at each reversal the poles become feebler until the oscillation dies away. The two cases of discharge are like a deflected pendulum swinging in a viscid liquid and in air. In the liquid, the pendulum will fall to its position of repose without oscillation; in air, it comes to rest after many oscillations of diminishing amplitude.

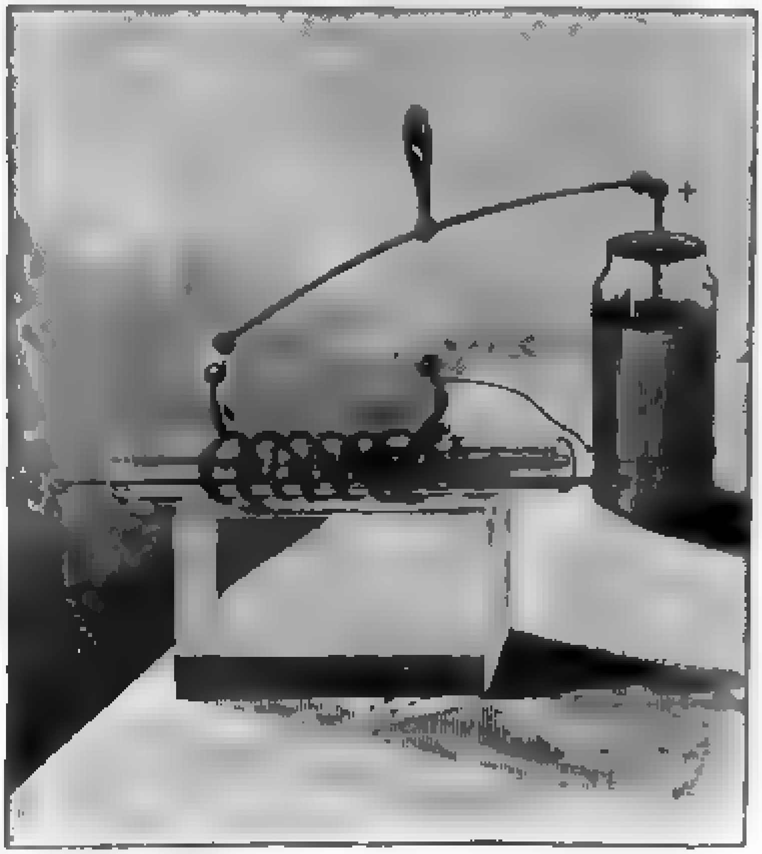


FIG. 350.—MAGNETIZING EFFECT OF SPARK ON STEEL BAR.

Should the experiment be repeated with the steel bar reversed in position, the polarity of the steel will be reversed. The north pole will still be to the left. If, however, the + charge is led around the coil in the opposite direction, the north pole will be to the right hand, in accordance with the rule before given.

Another Magnetic Action of the Discharge.—Suppose the two terminals of the Holtz machine to be connected by means of binding screws with a wire wound in a coil around a suspended magnetic needle, consisting of several

bits of watch-spring pasted on the back of a small mirror. Let the mirror hang on a silk fiber attached to a support on the coil. The position of the mirror is determined by the little magnets upon it, as they set in a north and south direction like a compass-needle. A beam of light is thrown upon the mirror and reflected upon a scale, A. Any motion of the mirror is revealed by the motion of the spot of light upon the scale. This device is shown in diagram, Fig. 351, where the coil is greatly enlarged; while the real instrument is represented in Fig. 352. Such an instrument is called a Galvanometer.

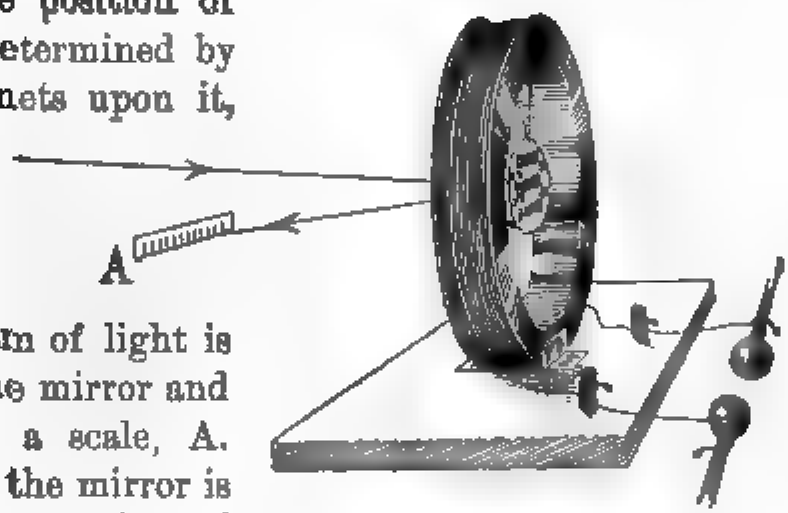


FIG. 351.—PRINCIPLE OF THE MIRROR GALVANOMETER.

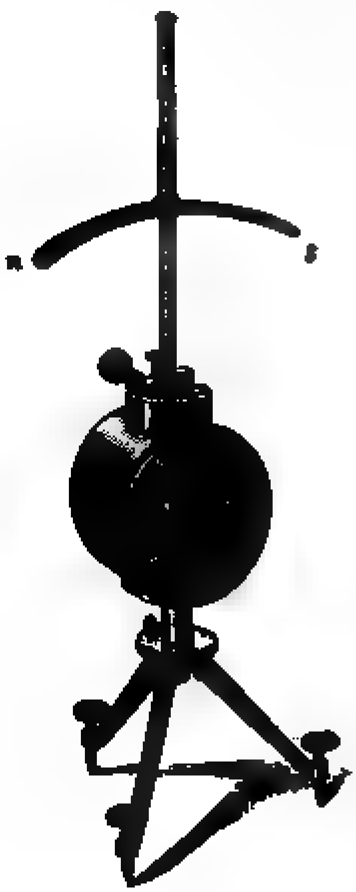


FIG. 352.—THE MIRROR GALVANOMETER.

The coil is composed of a large number of windings, and is covered with a brass case for protection. The mirror-needle is made sensitive by a larger magnet (*n s*, Fig. 352), which also points north and south, but has its poles so placed that it tends to turn the suspended needles about, end for end. When the large magnet is slipped down upon its supporting rod until the suspended needle is almost on the point of reversing its position, the latter is then extremely sensitive to the action of any other magnet.

If the Holtz machine is now turned, the positive electricity pours from the + knob through the wire of the galvanometer to the — knob. The mirror-needle is deflected and the watch-spring magnets all tend to turn east and west, or into a longitudinal position

within the coil. This action is opposed by the unbalanced part of the attraction of the earth, which tends to keep the mirror-magnets in a north and south direction. The mirror comes to rest in an intermediate position, when these two forces balance.

If the effect of the earth on the needle were to be wholly balanced by the reverse effect of the bar *n s* of Fig. 352, the effect of the discharge through the coil would be to turn the mirror-magnets exactly into a longitudinal position.

In such experiments the Leyden-jars should all be removed from the Holtz machine in order to avoid the danger of the destruction of the insulation in the coil by a spark.

The Electric Current. — When the wheel of the Holtz machine is turned while the knobs are connected with the galvanometer, as in the previous experiment, a continuous discharge pours through the wire, producing a constant deflection of the needle. As soon as the machine is stopped, the discharge ceases. Such a flow of electricity along a wire is called an Electric Current.

The current is maintained by means of the work applied to the crank of the machine, in the same way that a current of water can be maintained in a pipe circuit by means of work applied to operate a pump.

Other properties of an electrical current will be explained more fully after means for producing stronger currents have been treated. The voltaic battery, described in the following chapter, is simply a machine which by chemical action gives rise to a continuous electric current.

QUESTIONS.—Describe a battery of Leyden-jars. How are their outer coatings placed in communication? How, their knobs? Why is such a combination called a battery? *On account of its powerful effects.* May the discharge be dangerous? Relate an experience of Prof. Van Musschenbroek. On what does the effect of the electrical spark depend? How are bad conductors affected? Describe experiments in which the spark may be made to puncture a book; a piece of glass. What are Geissler tubes? Describe the discharge in rarefied gases. Will the spark traverse a vacuum?

Explain the discharge in air and the analogy between it and the discharge in the Geissler tube. State the condition of air-particles along the line of the discharge. When does Lightning occur? Describe lightning-flashes as illustrated by instantaneous photographs. How may you calculate their distance from you? For what is the lightning-rod intended? How are disasters averted through its agency? What should be the height of the rod? How much space

does it protect? To what depth should it extend into the ground, and why? Is it necessary to point lightning-rods? Account for the duration of thunder; the sudden crash after a moment of silence. What is the duration of a lightning-flash? Prove your answer. What places are most dangerous during a thunder-storm? Why is it safe to be in bed? Explain the Aurora.

Describe the magnetizing effect of the spark on a steel needle. Explain the Mirror Galvanometer; the action of the curved magnet; the effect of the passage of electricity through the coil of wire. Define an Electric Current. Can you give a reason for the purity of the air after an electric storm? (Suggestion: Ozone possesses remarkable chemical activity; it is a powerful corroder and deodorizer.)

EXPERIMENTS IN FRICTIONAL ELECTRICITY.—The pupil may construct the apparatus necessary for the following experiments: ELECTRIC BELLS.—Suspend two toy bells from a frame, and hang a brass button between them. Connect one of the bells with the conductor of a machine, and the other with the ground. When the machine is in action, the button is attracted to the first bell, strikes it, becomes itself charged by the contact, and is repelled till it strikes the second bell. Its positive electricity is thus discharged, and it falls back, to be again attracted and repelled. DANCING IMAGES.—On a metallic plate supported by some conducting substance, place several light figures cut out of pith, paper, or cork, and three or four inches above them suspend another plate from the conductor. As soon as the machine is worked, the figures will dance up and down from one plate to another in a laughable manner. Explain the principle. THE ELECTRIC KISS.—Attempt to kiss a person on an insulating stool, while he holds a chain connected with the conductor of an electrical machine in action. DIVERGING THREADS.—Tie together at each end a cut skein of twenty linen threads, about ten inches in length. Attach them to a conductor, and when the machine is operated they will assume an oval form. Why? ELECTRIFIED HAIR.—Fix a heavy copper wire to a doll's head furnished with hair, and insert the wire in one of the holes in the conductor of your machine. When the plate is turned, the hairs will stand grotesquely on end. Draw off the electricity by presenting your knife-blade, and they at once fall. MULTIPLICATION OF THE ELECTRIC SPARK.—When the continuity of a conductor is broken, sparks dart from one part of it to another. Paste pieces of tin-foil about one eighth inch apart on a length of glass tube, furnish the tube with tin caps, and place one cap in communication with the conductor and the other with the ground. As the sparks pass, the pattern is rendered luminous. A glass globe may be substituted for the tube.

VOLTAIC ELECTRICITY.—CELLS AND BATTERIES.

The Voltaic Cell.—If a piece of zinc be dipped in dilute sulphuric acid, the zinc will be attacked by the acid and replace hydrogen in it. The zinc and hydrogen sulphate become hydrogen and zinc sulphate. The hydrogen appears in bubbles on the zinc, and passes off as a gas. At the same time, for each gramme of zinc consumed, a definite amount of heat is evolved; the liquid becomes warm.

If a piece of heavy sheet-zinc be placed in dilute sulphuric acid (about one part sulphuric acid to nine or ten of water) and connected by means of a wire, M, with a strip of copper, C, dipped in the same solution, the zinc will still be found to dissolve; but the hydrogen bubbles will now form on the surface of the copper strip as well as on the zinc. If a little mercury be rubbed over the zinc, no gas will now form thereon; but when the copper and zinc plates are metallically connected, either by a wire, as in Fig. 853, or by touching them together above or below the liquid, the hydrogen gas all appears on the surface of the copper. After the zinc has been amalgamated with the mercury, it is best not to touch the copper plate to it, as the copper will also amalgamate.

FIG. 853.—VOLTAIC CELL.

Properties of the Voltaic Cell.—The wire which connects the copper and zinc plates of the voltaic cell has many interesting properties so long as it is in contact with them. When examined with delicate instruments, it will be found to be heated. It will magnetize iron, and will deflect a magnetic needle. In short, its properties show that a continuous discharge of electricity is pouring through it, the + discharge being from the copper to the zinc. This may be proved by replacing the wire M with the wire of the galvanometer coil; the deflection of the needle shows that a current is passing through the coil, and by reversing the connections the needle is deflected in the opposite direction.

The discovery that the source of electricity in such a case is *the contact of unlike substances* was made about 1800 by Alessandro Volta, Professor of Physics at Pavia (*pah-ve'ah*), and from him electricity produced in this way is called *Volta'ic*,* although identical with that

* The earliest discovery made in connection with this kind of electricity was that of Galvani (*gal-vah'ne*), Professor of Anatomy at Bologna, that the contact

obtained from electrical machines. Volta's celebrated Pile consisted of a series of pairs of copper and zinc plates, separated from one another by pieces of wet cloth. The whole was insulated, and a wire attached to each end. When the wires were brought together or separated, a spark was produced, and a person taking one of the wires in each hand received a shock.

The effects of Voltaic electricity may be familiarly illustrated. Place a piece of zinc under the tongue, and on the tongue a silver coin. As long as the metals do not touch, nothing is perceived; but as soon as they are brought in contact, the Voltaic circuit is formed, a thrilling sensation is felt in the tongue, and a taste like copperas is perceptible; if the eyes are closed, a faint flash of light is seen. Here electricity is developed by the chemical action of saliva upon the zinc.

Lay a silver dollar on a sheet of zinc, and on the coin place a living snail or angle-worm. No sooner does the creature, in moving about, get partly off the dollar and on the zinc, than it receives a shock and recoils. In this case, it is the slime of the snail or worm that acts chemically on the zinc.

Materials used in a Voltaic Cell.—The plates of the voltaic cell may be made of any two metals which are unequally acted upon by the liquid in which they dip, the object being to produce a difference of potential. The liquid may be either pure or acidulated water, or salt solutions of various kinds.

The choice of materials is determined by the use which is to be made of the cells, the trouble of keeping the cell in order, and the presence or absence of offensive fumes which may result from the chemical action in the cell.

In all forms of battery in practical use, zinc serves as the plate which is to be most acted upon. The other plate is usually of copper, platinum, or carbon, and is not acted upon at all.

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of metals produces muscular contraction in the hind-legs of a frog (1790). Galvani's experiment is often repeated at the present day. Separate the legs of a frog from the body, skin them, lay a thin curved zinc rod under the nerves of the loin, and touch the muscles of one leg with a similar rod of copper. The instant the rods are brought in contact, the leg will be convulsed. Galvani believed these movements to be caused by the passage of electricity from the nerves to the muscles, through the metal rods which served as conductors.

A battery may be made of two zinc plates, one of which has been cast and the other hard rolled. Even a difference of temperature between two plates, otherwise precisely alike, will give a feeble electrical current. When the two plates are exactly alike, whether they are acted upon by the liquid or not, no current will result.

Local Action upon the Battery-Plate.—Neighboring points upon a plate of commercial zinc are always sufficiently unlike to produce a current between them. One point in the plate may be harder than another near by, or it may be under a different pressure by reason of internal stresses developed in solidification; or impurities may exist in different degrees at the two points. All these conditions will result in setting up local currents upon the plate, which is thus dissolved without producing electrical action through the connecting wire.

When mercury is rubbed over the plate, it dissolves the zinc, obliterating the effects of internal stresses, but does not dissolve such impurities as carbon or iron which float out into the liquid. A clean, homogeneous surface of zinc is thus exposed to the liquid. The zinc does not dissolve in the acid except when the plates of the cell are connected by the wire *w*, or some conductor other than the liquid in which both are dipped. The current then pours through the connecting wire.

Polarization of the Battery-Plate.—After the battery has been in action for a short time, the copper plate becomes covered with a film of hydrogen. The cell is then said to be *polarized*. While the plate is in this condition, the current is much feebler than when it is clean. This is shown by means of the galvanometer. The deflection of the needle diminishes as the current becomes feebler. The hydrogen can be brushed off the plate by mechanical means, or may be removed by lifting the plate into the air. These methods are not very effective, as the hydrogen immediately reappears on the plate. The most effective way of removing it is by immersing the copper plate in some liquid which will combine chemically with the hydrogen as it appears. The cells next to be described are designed for this purpose.

The Gravity Cell.—In this cell, the copper is placed in a solution of copper sulphate (blue vitriol) in the lower part of the vessel. The zinc is suspended in the upper part of the cell, in a solution of zinc sulphate. The copper sulphate solution has a higher specific gravity than the zinc sulphate, and this keeps the two liquids separate. An insulated wire, having an exposed end fastened to the copper by a rivet, passes out of the top of the cell and forms the + wire of the cell. The negative wire is usually clamped in a binding screw attached to the zinc above the liquid.

FIG. 354.—GRAVITY CELL.

When the hydrogen appears on the copper plate, surrounded by the copper sulphate solution, it replaces the copper of the copper sulphate. Instead of hydrogen and copper sulphate, we have copper, which is deposited on the copper plate, and hydrogen sulphate (sulphuric acid). As a result, therefore, copper instead of hydrogen is deposited on the copper plate. The sulphuric acid diffuses through the liquid and attacks the zinc, forming zinc sulphate. The zinc is thus continually dissolved. The copper sulphate is also consumed, and is replaced by dropping in a few crystals of the substance whenever the blue color in the lower solution has nearly disappeared. The lighter zinc sulphate solution must occasionally be siphoned off with a rubber tube, and water should be poured in carefully.

In a dry room, evaporation at the top of the liquid causes crystals of zinc sulphate to form on the jar just above the liquid. The liquid rises through these crystals by capillary action, and crystals form higher up. Thus the salt moistened with liquid will finally creep over the top of the jar and down upon the shelf and floor. This is prevented by brushing a little raw linseed-oil upon the glass above the liquid.

Various forms of the gravity cell are used by thousands in telegraphing. Both the zinc and copper plates are made in various patterns. In the older Daniell cell, the two liquids were separated by a porous jar of earthenware.

In the Grove Cell, nitric acid is used in place of the copper sulphate solution, and for the same purpose.

As copper is rapidly acted upon by nitric acid, Grove substituted platinum. In Fig. 355, P is the platinum sheet, placed in a porous jar containing the acid. The zinc is bent in a U-form around the porous jar. The whole is placed in a jar of glazed earthenware, here shown broken away to reveal the interior parts. The outer jar contains dilute sulphuric acid in contact with the zinc.

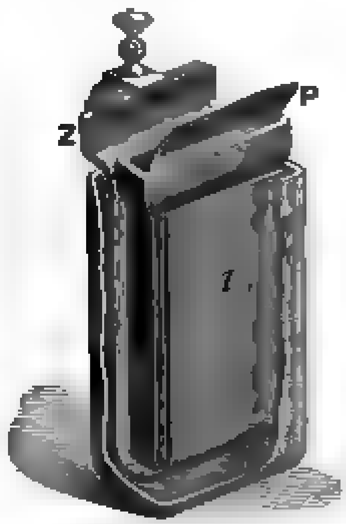

FIG. 355.—THE GROVE CELL.

The Bunsen Cell differs from that of Grove only by the substitution of a stick of carbon, made from gas coke, for the platinum sheet. This cell, when worked through short, heavy wires, gives better results than the gravity cell; but the liquids must be replaced after a few hours of action, and this occasions trouble and expense. The Bunsen cell also gives off corrosive fumes, due to the decomposition of the nitric acid by the hydrogen (see page 471).

A solution of 4 parts of sodium bichromate, 4 of sulphuric acid, and 18 of water, may replace the nitric acid in the Bunsen cell. This solution gives off no fumes. The bichromate salt is dissolved in water, and the sulphuric acid slowly added, while the liquid is stirred.*


FIG. 356.—LECLANCHÉ CELL.

The Leclanché Cell is shown in Fig. 356. The zinc is usually in the form of a rod,

* Water should never be poured into sulphuric acid; the heat developed is great enough to vaporize the water explosively, and serious accidents may occur The acid must be poured slowly into the water; stir, as you pour, with a glass rod.

which stands in one corner of the outer vessel. The porous jar contains the carbon plate packed in fragments of coke and powdered manganese dioxide, which acts in oxidizing the hydrogen-bubbles. The liquid is a solution of ammonium chloride in water.

This cell, having small power, is much used in working house-bells, telephones, railway-signals, etc., where it is required only occasionally and for a short time. It will not stand continuous work like the gravity cell, as the manganese oxide acts slowly and the cell polarizes, requiring time to recover. The advantage of the Leclanché cell is, that it may be closed up in a box to prevent evaporation and left for a year without attention.

Dip-Batteries.—Various forms of cells have been constructed, which allow the zinc plates to be lifted from the solution when not in actual use.

In the bichromate of potash cell, shown in Fig. 357, usually made in bottle-form, the zinc is carried on a rod held

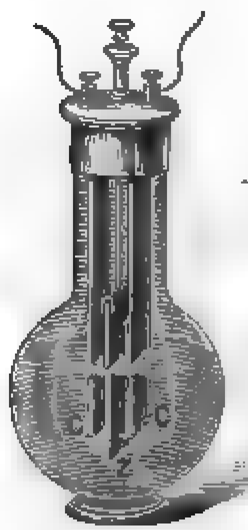

FIG. 357.—BICHROMATE BOTTLE CELL.

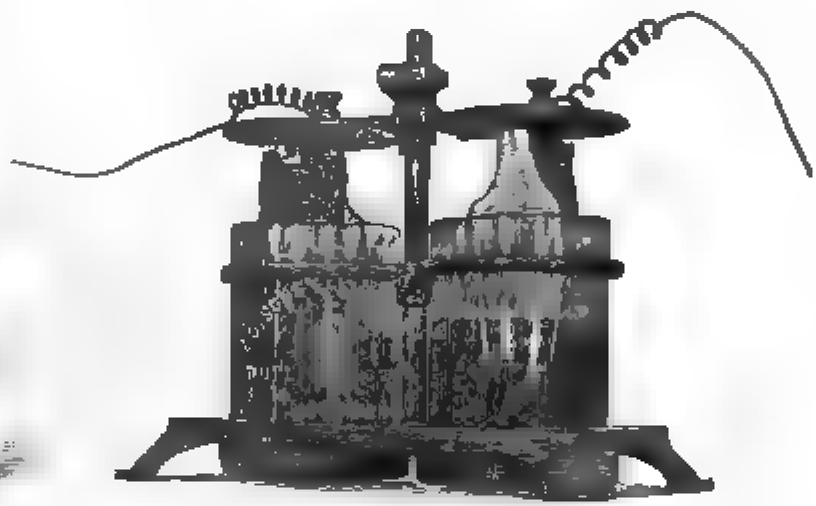

FIG. 358.—DIP CELLS USED WITH THE EDISON ELECTRIC PEN.

by gentle friction in a sleeve at the top of the cell. By pulling upward upon the rod, the zinc may be raised.

In Fig. 358 all the plates of two cells are attached to a cross-piece which slides upon a vertical rod between the cells. The rod is mounted upon a bed-plate of iron, upon which the cells also rest. The plates are held in position

when out of the solutions by means of a gravity latch-piece, which drops into a notch in the vertical rod. One liquid only, the bichromate of potash solution, is used. It yields no noxious fumes, and is in that regard preferable to nitric acid. Hence these cells are much used for table-work.

Arrangement of Cells in a Battery.—When the wires leading to a galvanometer are attached to the zinc and carbon plates of a battery cell, instead of to the knobs of the electric machine, as in Fig. 351, the mirror-needle is permanently deflected. This shows that a current of electricity is flowing in the wire. The stronger the current, the greater the angle of deflection of the needle.

If it is desired to get a stronger current than is given by one cell, a number of cells may be connected so as to act together. In Fig. 359 four cells are joined, the zinc of each being connected with the carbon or copper of the next.

The current from each cell then flows through all the others. Cells thus arranged are said to be *in series.*

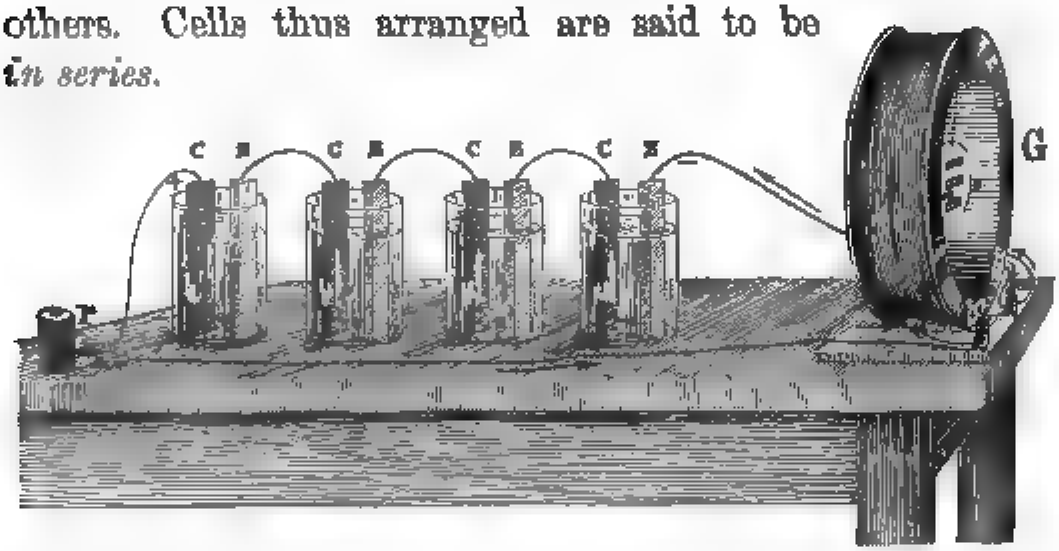

FIG. 359.—ARRANGEMENT OF CELLS TO FORM A BATTERY—IN SERIES.

In Fig. 360, the four cells have their zincs all connected by a metal conductor, the coppers or carbons being similarly connected. These main conductors are then connected by wires with the galvanometer. Such cells are said to be connected *in multiple* or *in parallel circuit.*

When the cells are in multiple, the current from any one cell does not flow through any other cell, but the separate currents are forced out in parallel streams through the conducting wires and galvanometer.

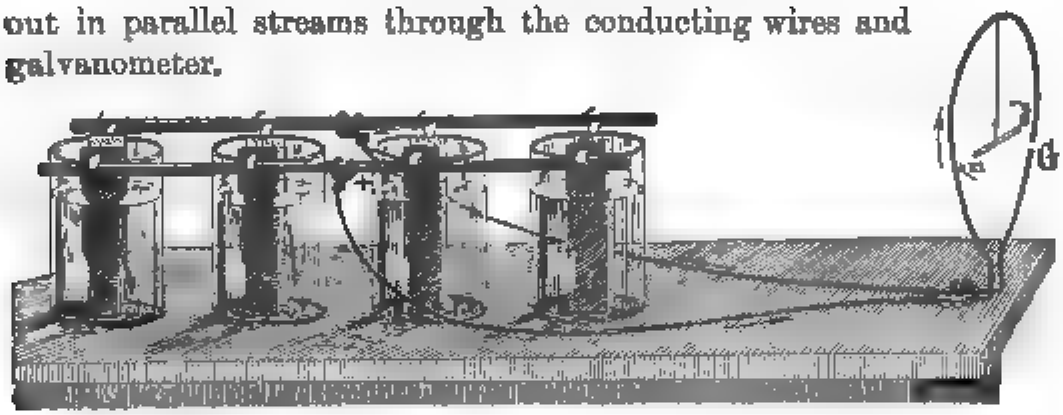

FIG. 360.—ARRANGEMENT OF CELLS TO FORM A BATTERY—IN PARALLEL CIRCUIT.

The Proper Arrangement of the Cells of a battery depends entirely upon the kind of battery used, and the nature of the external circuit.

If it is desired to send a current through a long, thin wire, and one cell gives an insufficient current, other cells must be added in series, as in Fig. 359. The longer and smaller the wire, the greater the number of cells required. If a coil of wire, r (Fig. 359), be connected in the circuit, the current will become feebler. More cells must be added in series in order to force the same current as before through the circuit.

If the circuit is made up of large copper wires, connected with a galvanometer consisting of one turn of large wire, then, if one cell gives an insufficient effect, the added cells should be in multiple. The current is not materially increased by adding cells in series with the short, large conductors of Fig. 360, nor by adding them in multiple with the long fine wires of Fig. 359. It appears that the conducting wires offer a resistance to the passage of the electricity; that this resistance increases with the length of the conductor, and diminishes as the size of the wire increases.

The battery acts in a twofold way. It drives the current through the wire and also serves as a conductor, since the current must flow through the battery. If the battery-plates are small, the effect is to

make the resistance great, as is the case with a wire when its section is small. In Fig. 360, if only one cell is acting, its resistance is large as compared with that of the wire conductors. If the three other cells be added in multiple, they will act precisely as one cell of four times the section. The effect is to diminish the battery resistance to one fourth of that of one cell, the battery resistance comprising nearly the whole resistance. The power of the four cells for driving electricity through the wire when thus connected is the same as for one cell, as will be shown later (page 480).

In Fig. 359 the resistance of one cell is small compared with that of the long, fine wire. When the three cells are added in line, the battery resistance is made four times as great, since it amounts to an increase in the length of the conductor; but the battery resistance is still insignificant as compared with that of the wire. The resistance of the whole circuit has not, therefore, been materially changed; but the power of the battery to drive electricity through resistance is four times as great. Hence an increase of the current results.

Analogy between the Action of Pumps and Batteries.—Suppose it is desired to force a gallon of water a second through a long, narrow pipe (R, Fig. 361). A pump of large section operated by a man is found to drive only about a quarter of the required amount. Four such pumps may then be connected in series, so that the water passes through them all, as shown in the figure. If the pistons are worked in unison, the driving force is four times as great as when only one pump is worked, and the amount of water discharged a second will be very nearly four times as great.

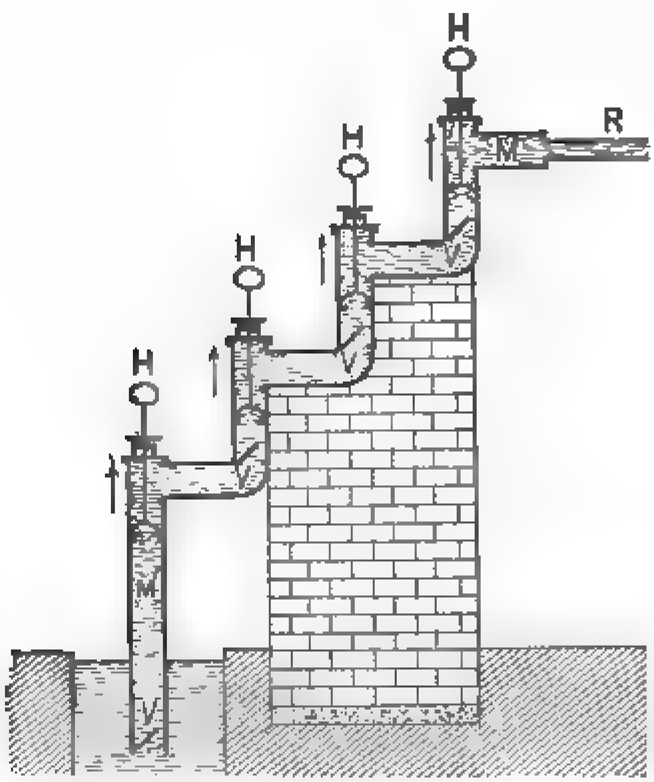

Fig. 361.—Illustrating Pumps in Series.

If, however, water is to be forced through a very large tube, R, as in Fig. 362, little will be gained by adding pumps in series, should one pump like those represented be insufficient. The water-current is throttled in the pump instead of in the conducting-pipe. The discharge may be increased by adding pumps in parallel, as in Fig. 362. The

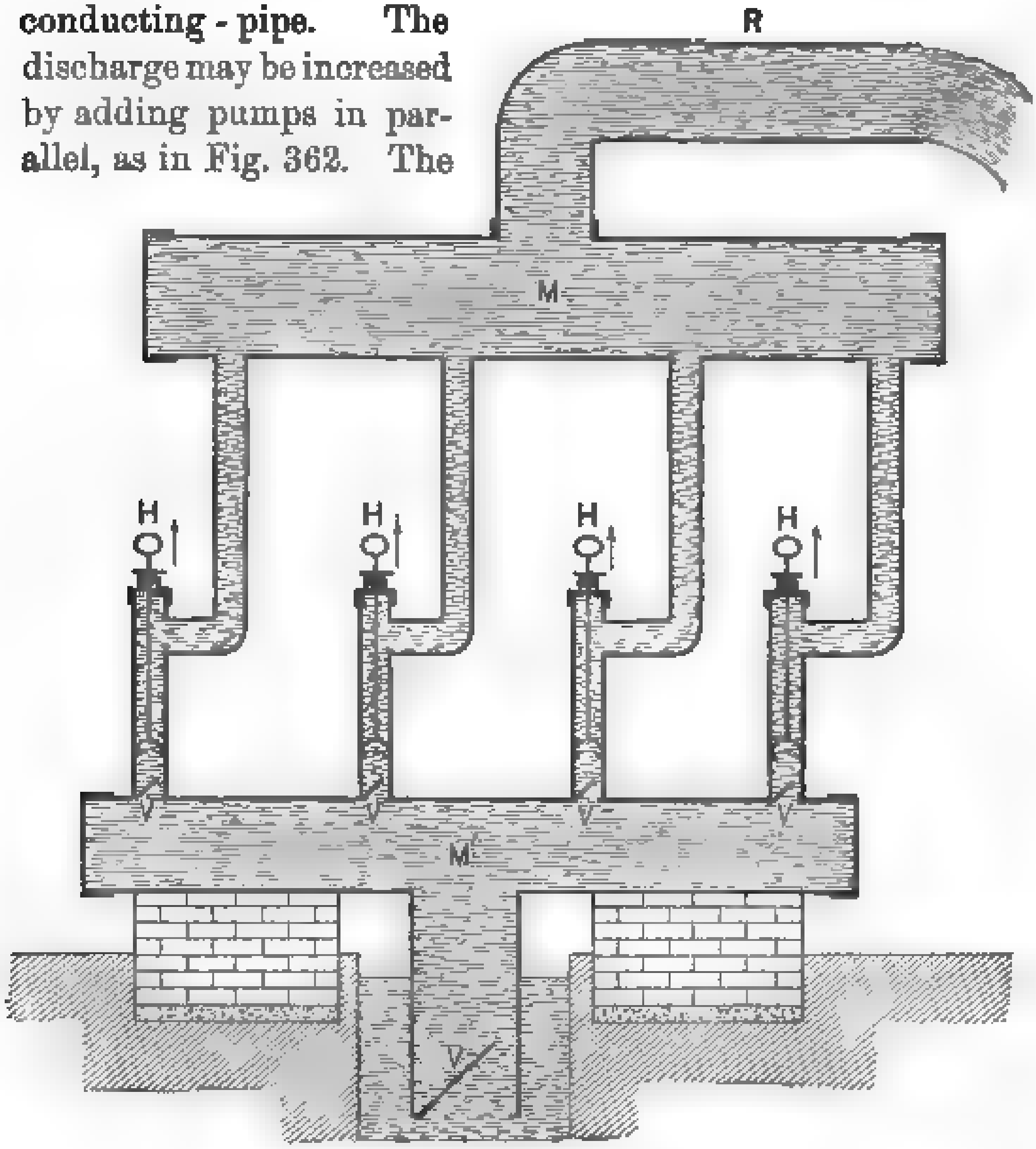

FIG. 362.—ILLUSTRATING PUMPS IN PARALLEL CIRCUIT.

pressure which drives the water is not thereby increased. The pumps balance one another. The four pumps simply act as one pump of greater section, but with no greater pressure per square inch.

Similarly, in an electric battery, if the current is throttled by high resistance in the conducting wire which it is not feasible to diminish, cells must be added in series to increase the electro-motive force sufficiently to drive the desired current through the resistance.

If the current is throttled in the battery, its resistance may be diminished by increasing the sectional area of the battery liquid through which it must flow. This is done by connecting cells in parallel, and an increase in the strength of the current will result.

QUESTIONS.—Define an Electric Current. *An electric current is a continuous transference of electricity between bodies having a difference of potential.* Apply this principle in a description of a Voltaic cell. How can you prove that the current flows from the copper to the zinc ? Why is electricity produced in this way called Voltaic ? Describe Galvani's experiments, and state his theory. Give Volta's correction of this theory. Describe the Voltaic pile. Suggest some familiar illustrations of Voltaic electricity.

Enumerate the materials used in the Voltaic cell. Prove that the source of Voltaic electricity is chemical decomposition. What is the cause of local currents, and how do they affect the action of a cell ? State the effect of rubbing mercury on the zinc plate. What is meant by polarization of the plate ? How is it corrected ? Explain, with the aid of sketches, the gravity, Grove, Bunsen, Leclanché, and bichromate cells. Why is the latter preferred for table-work ? Describe the arrangement of cells in a battery in series ; in multiple or parallel. On what does the proper arrangement of the cells depend ? Explain your answer. In what two ways does a battery act ? Compare with the action of pumps differently arranged.

If a charged battery is to be kept for some time ready for use, why is it important to take care that the ends of the wires are not connected outside the battery ? To detect the presence of a bullet or piece of metal in the tissues, a probe is used consisting of two pieces of insulated wire attached to small plates of zinc and copper. The copper is placed on one side of the tongue, the zinc on the other, and the wound is probed. State how the surgeon will be made aware of the presence of the metallic body when the tips of the wires touch it. Explain the principle. Sum up the differences you have observed between the current from a Voltaic battery and that from a Holtz machine, as regards intensity, ease of production, heating and magnetic effects, power of chemical decomposition, and impression on the nervous system.

ELECTRICAL RESISTANCE.—THE OHM.

Unit of Electrical Resistance.—When electricity flows through any medium or circuit, it meets with resistance. We can always determine how much greater is the resistance offered by any piece of wire than that offered by some standard of resistance.

The unit of resistance, called the Ohm (*ome*), is the re-

sistance of a column of pure mercury having a section of one square millimetre and a length of 106·28 centimetres at a temperature of 0° C. A copper wire having the same section and resistance must have a length of 6,090 centimetres, and a German-silver wire, a length of 485·4 centimetres.

Conductors of the same size and having twice these lengths, will have a resistance of two ohms. Thus the resistance is proportional to the lengths. If wires twice as thick are used, the resistance is one half as great. Thus, a copper wire, having a length of twenty feet and a section of two square millimetres, will have the same resistance as a wire of the same material ten feet in length and one square millimetre in section.

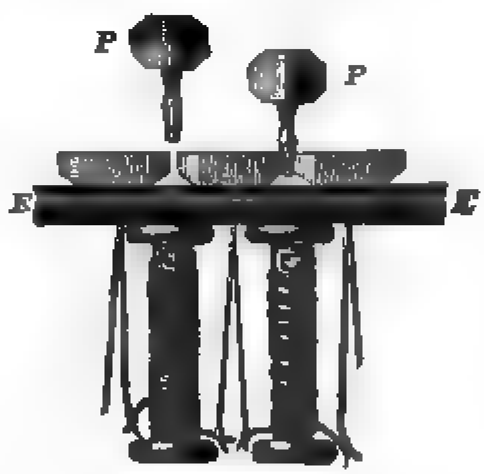

Fig. 363.—Resistance Coils.

Resistance Coils.—Coils of wire having known resistances can be purchased of instrument-makers. They are arranged as shown in Fig. 363. The wire is wound upon a spool, like thread, and is doubled upon itself at the middle, the two halves being wound side by side. The coils do not then become magnets when a current passes through them.

The spools are fastened on the under side of the cover of a box in which many such spools are mounted. The ends of the wires connect with other wires which pass up through the cover, and are soldered to heavy brass bars, $C^1C^2C^3$. These bars can be connected with one another by means of metallic plugs, P, P (Fig. 363), thus forming a continuous conductor.

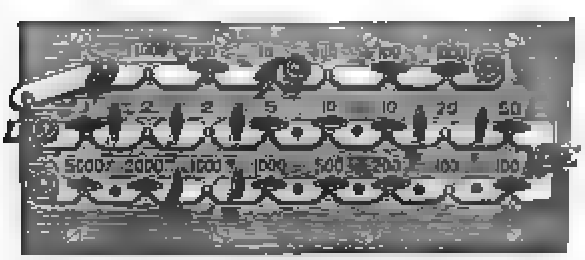
Fig. 364.—Set of Connected Bars, Resistance-Box.

If the wires of a battery are connected with the extremities D F (Fig. 364) of such a set of connected bars, all having coils beneath, t

current will flow through the bars and plugs, which offer only an insignificant resistance by reason of their large size. If any plug is pulled out, the current must then flow through the coil of wire beneath, whose resistance is thus added to the circuit.

Coils in a Resistance-Box.—The coils of an ordinary resistance-box are as follows:

1	2	2	5	10	10	20	50
5000	2000	1000	1000	500	200	100	100

The coil marked 1 is composed of a wire whose resistance is one ohm. The two-ohm coil, if made of wire of the same size, must be twice as long, etc. The higher resistances, like 1,000 ohms, are usually made of very much smaller wire than that comprising the smaller resistances; the coils would otherwise become too large. By properly choosing the sizes of the wire, the coils can all be made of about the same size.

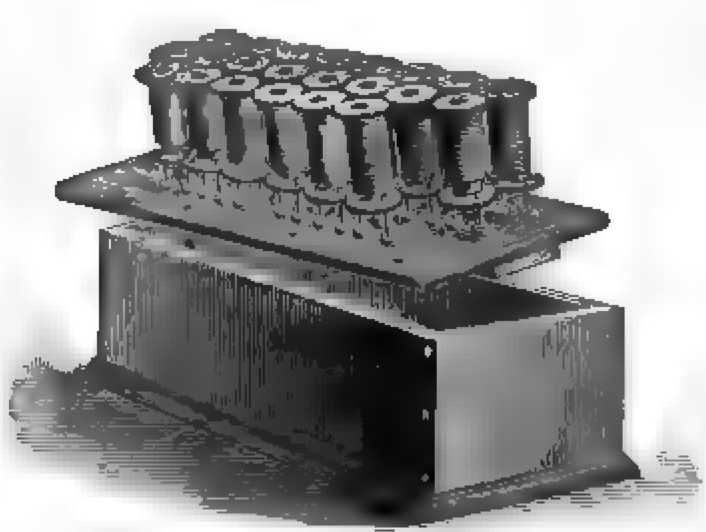

Fig. 365.—Interior of Box of Coils.

A set of coils lifted out of the box is shown in Fig. 365. A box like the one described above will measure any resistance between 1 and 10,000 ohms.

Standard Resistances.—Let a standard coil be placed in a water-tight metal box, and the ends of the wire connected with large copper conductors (W, W, Fig. 366), which when in use dip into small dishes of mercury, serving as connections. As the resistance of all substances varies with temperature, these coils are standard at some definite temperature. When in use, the coil is immersed in water, the temperature of which is measured by a thermometer.

The corrections for temperature are similar to those which must be applied to a metre-bar in order to allow for expansion.

The increase in resistance for each ohm when heated through 1° C. is for copper wire 0·0038 ohm; and for German silver (composed of copper 4 parts, nickel 2 parts, zinc 1 part) the coefficient per ohm-degree C. is 0·00044. Thus 100 ohms of copper at 0° C. become $100 + 100 \times 25 \times 0{\cdot}0038 =$ 109·50 ohms at 25° C.

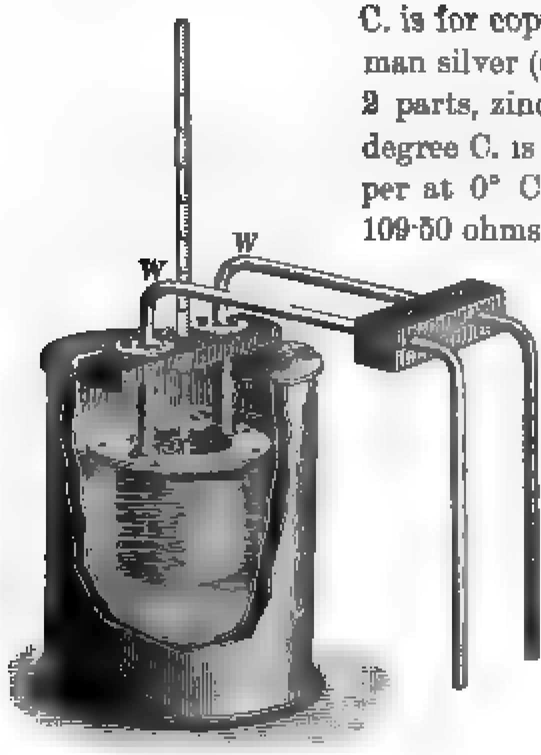

FIG. 366.—STANDARD COIL IMMERSED IN WATER.

The Measurement of Resistances. — To measure the resistance of a telegraph line, the distant end is connected with the ground, as at G′ (Fig. 367), by means of a gas or water pipe system. In the absence of these, a gas-pipe may be driven down to moist earth, and water may be poured into the hole around the pipe. A well into which an iron rod dips may also be used. One plate of the battery, B, is also grounded at G. The other plate is connected with the line at D through a delicate galvanometer, V, and the resistance-box, R, the plugs being all in place.

The galvanometer-needle is deflected and its position is noted. The line is then disconnected at D, and the battery wire at C is disconnected and attached to D. Resistances are then introduced by pulling plugs from the box until the needle is again at the same position. The coils within the box form an artificial line, and their resistance is equal to that of the actual line. In the first measurement, the earth is excluded, but it is so large that its resistance is insignificant if good connections are made at the earth plates, G and G′.

This is learned by measuring two grounded wires upon the same poles between any two stations, as New York and Washington. The distant ends are then disconnected from the ground and connected with each other. The near ends are also disconnected from the ground

and connected with binding screws at C and D. The two wires then form a loop from the testing-table in New York to Washington and back. The resistance of the two lines in this measurement is found

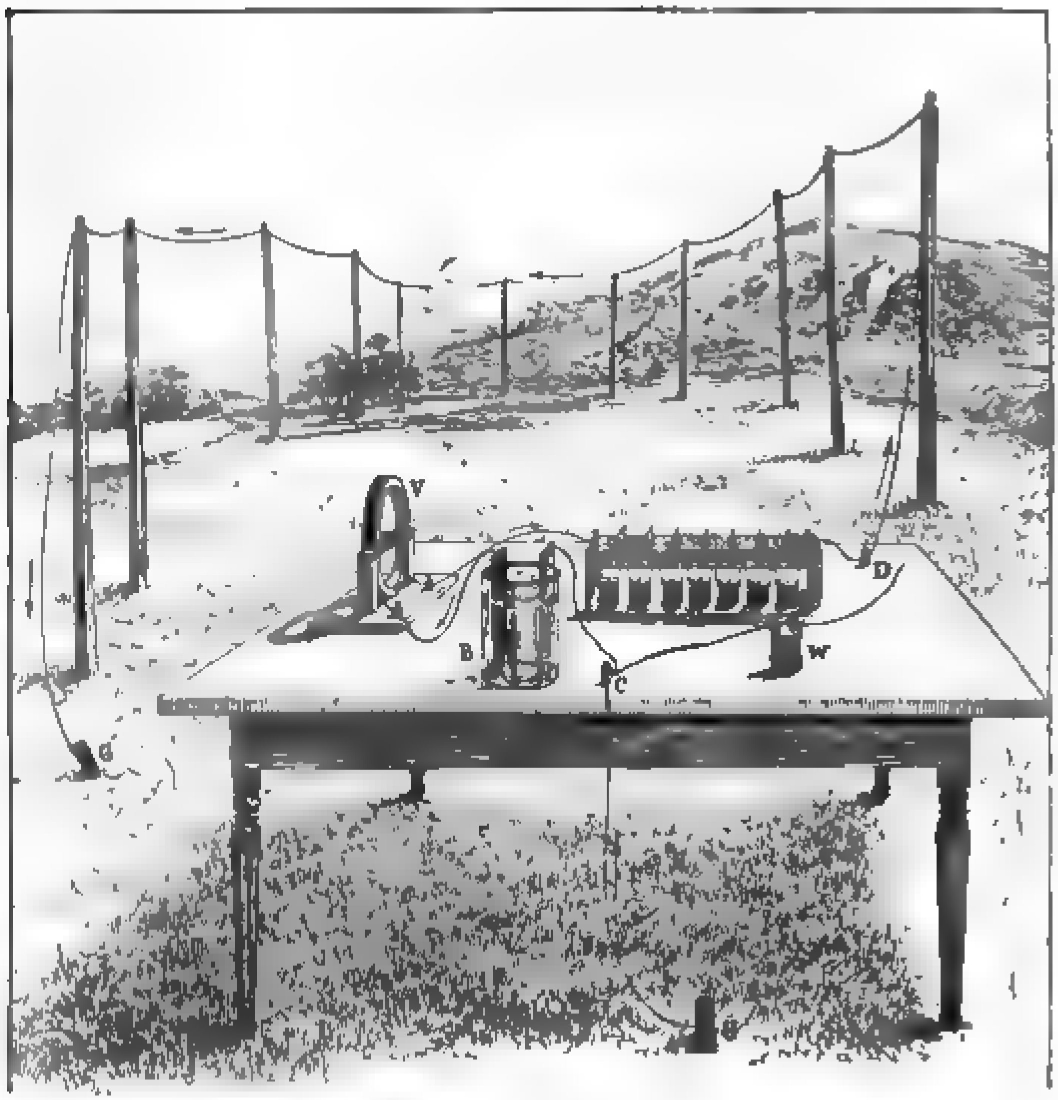

FIG. 367.—MEASUREMENT OF RESISTANCE.

to be the same as the sum of the resistances of the lines when grounded. This shows that the earth between New York and Washington has practically no resistance.

In the loop measurement, the two wires are connected into the circuit exactly as the wire coil, W, would be if its extremities were connected at C and D, and the ground and line were disconnected at those points. The resistance of the coil W can evidently be found in the same way.

The resistance of No. 9 iron telegraph wires is about 16 ohms to the mile.

This way of ascertaining unknown resistance in terms of standard coils is like one method of finding the weight of a body; see page 84.

Measurement of Resistance by means of the Differential Galvanometer.—The differential galvanometer consists of two coils, W, of insulated copper wire (Fig. 368).

The coils should have the same number of windings, and should be as near alike in all respects as possible. They are

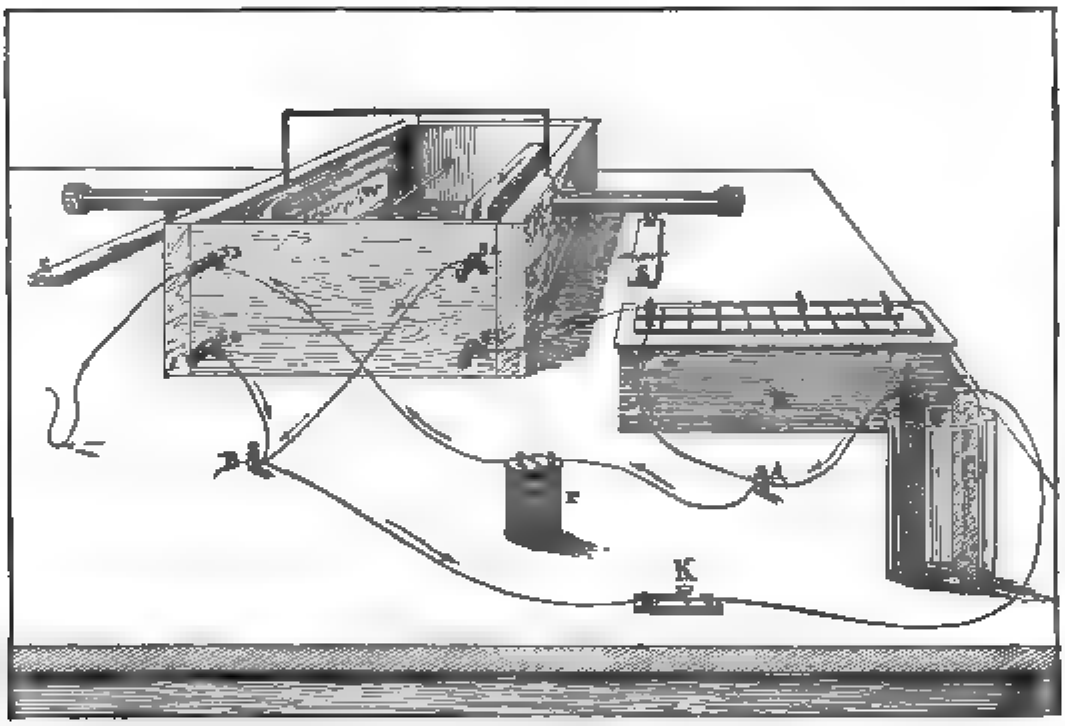

FIG. 368.—PRINCIPLE OF THE DIFFERENTIAL GALVANOMETER.

mounted on the ends of two rods which slide with gentle friction through the sides of a box. The ends of the wire forming the coils terminate in four binding screws upon the side of the box. Between the coils, suspended on a fiber of silk, is a small magnetized needle or other suitable magnet.

A wire from either end of a battery communicates at A with two branches, one of which connects with S through the plugged resistance-box, the other with S_2. The current is then led through the galvanometer coils to the screws S,

and S_4, from which wires uniting at B return the current to the other end of the battery. At any point in the battery line between A and B, a key, K, is fixed, by depressing which the circuit is closed.

The two coils of the galvanometer are so placed and connected that they tend to deflect the needle 90°, but in opposite directions when the key is closed. If the two branches have equal resistances, each will carry half of the battery current. They may be so adjusted by sliding one of the connecting wires through the binding screw, as at S_3. The position of the coils is adjusted by sliding them in or out on the rods. The adjustment is complete when opening and closing the key produces no deflection of the needle.

The needle is made more sensitive by means of two bar-magnets, N S, lying on the table parallel to it. If it sometimes points wrongly, the magnets N S may by patient adjustment be made to restore it to its proper position. The sensitiveness of the needle will also be increased by placing the coils nearer together.

Now connect the coil *r*, whose resistance is to be measured, with the branch not containing the resistance-box. The resistance of this coil obstructs the current in that branch, and more than half now flows through the other branch, the galvanometer coil of which has a greater effect than the one in the branch of greater resistance. If plugs are now pulled from the resistance-box until on opening and closing the key the needle is again in balance, the added resistance in the box is equal to that of the coil V.

This operation precisely resembles the determination of weights by a lever-balance of equal arms, where the unknown weight is counterpoised by standard weights.

Faults on Telegraph Lines and Cables.—When an overland line breaks, its resistance becomes practically infinite. The break is usually located without difficulty by simple inspection, so that electrical methods are unnecessary. In ocean cables it is important to locate the break in order that the cable may be grappled and raised as near as possible to the fault.

The resistance of a given cable in a perfect condition is known, being frequently measured. When the cable breaks, it makes a "ground" in the water. If this ground is one third of the way across

from the American to the foreign terminus, the resistance from the American side at once drops to one third of that determined by previous measurements, provided the foreign ground connection is broken. In a similar way the fault can be located by measurements from the foreign end, which will show a resistance of two thirds of the whole cable resistance.

Sometimes the fault is not complete, but involves merely leakage through a crack in the insulation. The fault itself will then have an appreciable resistance, and the measurement from the American end will locate the break too far away from our shore. Measurement from the foreign end will then locate it too far from the foreign shore, the fault-resistance being in each case measured with the fraction of cable. The sum of the two will be greater than the resistance of the perfect cable. The break then lies midway between the two points thus located.

Caution in measuring Resistance.—In all cases where the resistance of a coil, as W in Fig. 368, is to be measured, the coil must be far enough from the galvanometer not to deflect the needle directly. Such a coil when traversed by a current becomes an electro-magnet. It is to avoid such trouble that the wires of resistance-coils are doubled on themselves, as was previously explained.

QUESTIONS.—Explain Electrical Resistance. What is the Unit of Resistance called? Compare the resistance of a column of mercury with that of a copper and of a German-silver wire of the same length and section. State the relation between resistance and length of wire; between resistance and thickness of wire. What are resistance-coils? How are they connected with batteries? Describe a resistance-box. What is the effect of temperature on the resistance of substances? How are standard resistance-coils applied in measuring the resistance of telegraph lines? Compare the mode of ascertaining unknown resistance in terms of standard coils with a method of finding the weight of a body by the use of the spring-balance.

Describe the Differential Galvanometer, and explain its use in the measurement of resistance. Compare its operation with the determination of weight by a lever balance. What effect on its resistance has a break in an overland line? How are breaks in cables and underground wires located? Explain what occurs when the fault involves leakage merely. How is the place of leakage found? Why are the wires of resistance-coils doubled on themselves?

MEASUREMENT OF CURRENTS.—THE AMPÈRE.

The Unit of Current is called the Ampère (*am-pare'*). If a current is passed through a solution of copper sulphate (blue vitriol) by means of two copper plates having the form shown in Fig. 353, copper will be deposited on one plate and dissolved from the other. The plate connected with the zinc plate of the battery will receive a deposit of copper. The other plate will, if of pure copper, lose an equal amount. As it usually contains impurities which are in part washed off into the liquid, the loss of this plate is generally a little greater than the gain of the other.

An ampère will deposit 0·328 milligramme of copper a second, or 1·1833 grammes an hour.

A current of how many ampères will therefore deposit one kilogramme an hour? A current of how many ampères will deposit one pound an hour?

The amount of silver, copper, and gold deposited per hour by one ampère is given in the table below:—

SUBSTANCE.	Grammes per Ampère per hour.	SUBSTANCE.	Grammes per Ampère per hour.
Hydrogen	0·03738	Gold	2·44480
Silver	4·02500	Copper	1·18330

If the current is passed through water, the water is also decomposed into its constituent gases, hydrogen and oxygen. The hydrogen is liberated at the plate connected with the zinc plate of the battery, while oxygen forms at the other. These gases may be collected in tubes in the usual manner, and the amounts of gas are found by measuring the volumes (Fig. 369). The water must be slightly acidified in order to make it a good conductor.

The plates used for the decomposition of substances are called *electrodes*. The one attached to the zinc wire is called the negative electrode, or *cathode*, and the other is the *anode*. Hydrogen and metallic substances are deposited

on the cathode. In decomposing water, both electrodes are of platinum, in order that the gases set free may not act chemically upon them.

Relation of Electrodes and Battery-Plates.—In the battery, it was found that hydrogen forms on the plate toward which the current is flowing in the cell. The copper or carbon plate is surrounded by an oxidizing liquid, in order to remove the hydrogen as it is liberated. The acid is placed in contact with the zinc. In the decomposing cell, V (Fig. 370), the same thing is observed. Hydrogen and all metals appear on the plate toward which the current is flowing in the decomposing cell.

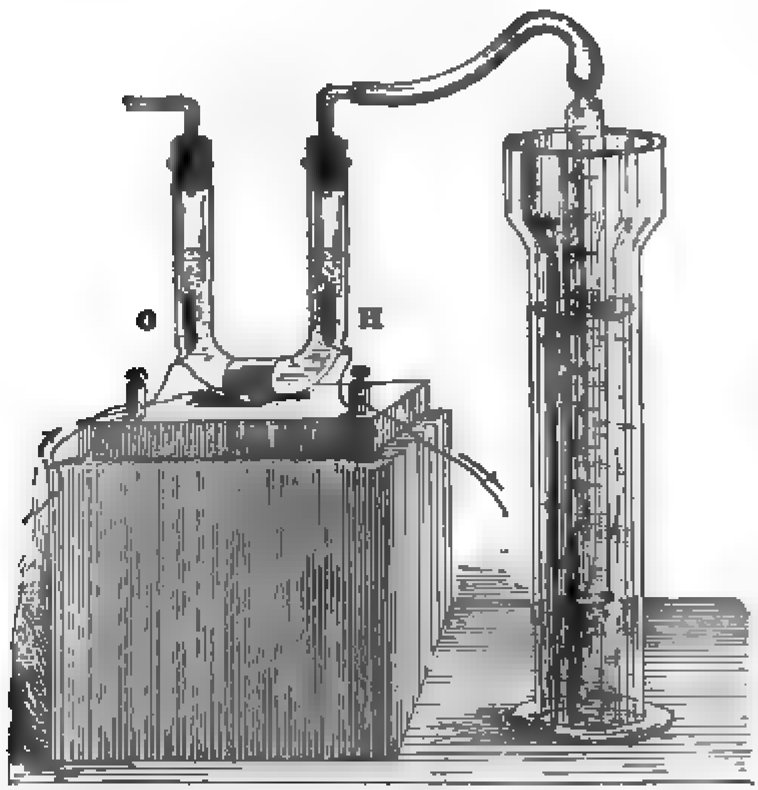

FIG. 369.—DECOMPOSITION OF WATER.

If a solution of copper sulphate is placed in V, the copper is deposited on the plate marked *a*, while the other plate will have around it an accumulation of sulphuric acid. In the gravity battery, copper deposits on the plate C, while the sulphuric acid is liberated around the zinc plate Z.

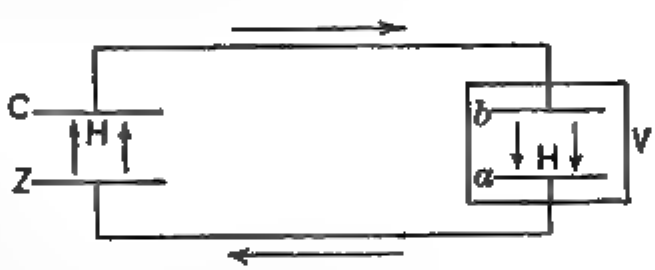

FIG. 370.—ACTION OF ELECTRODES.

If V is a large plating-vat, it is found that the electrodes act like a battery, but tend to send a current in the opposite direction from

that of the battery. If the battery is taken out of the circuit, this current is easily shown by the deflection of a galvanometer-needle. The current from the electrodes is always feebler than that from the battery, and when the two are connected the result is the enfeeblement of the battery current by the decomposing cell. The current from the electrodes, due to the chemical action, resists the battery current, which has brought about the chemical action. The polarization of the battery-plates themselves is an action of the same kind.

Measurement of Current by Magnetic Action.—If a wire which carries a current from several Grove cells is passed up through a small hole in a horizontal plate of glass or card board, and iron-filings are sprinkled upon the glass from a sifter, the filings will arrange themselves into lines like those produced by a magnet. The lines, however, are circular in form, having the wire as a center.

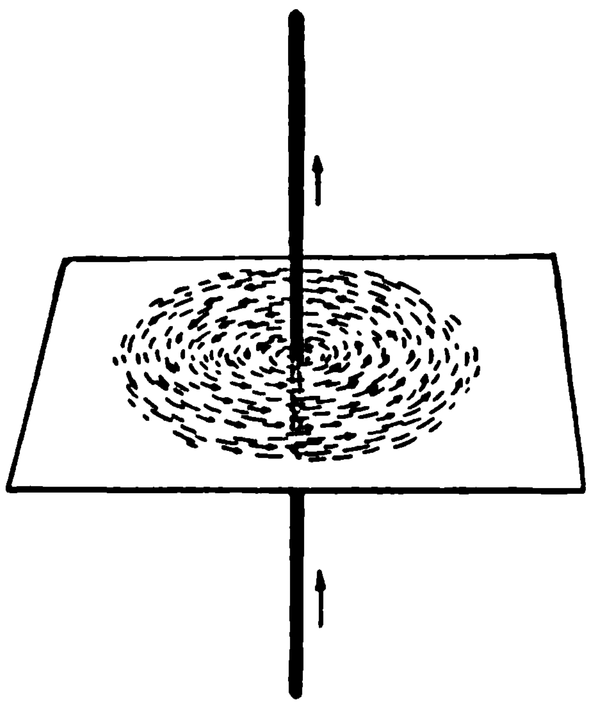

Fig. 371.—Arrangement of Iron-Filings on a Plate of Glass.

A magnetized sewing-needle balanced on a silk fiber or a fine hair will tend to set tangent to these lines. The direction of its north pole will be reversed when the current is reversed.

If a piece of steel had only a north pole and were acted upon only by the current, the pole would revolve round the wire in any one of the circles in which it might be placed when the current was started. A south pole would turn in the opposite direction. As every piece of steel has both poles, which are urged in opposite directions, the needle sets in the line of force.

In Fig. 371, the current passes upward through the wire, and the arrows on the plate indicate the direction in which the north pole points. This direction may be remembered by means of

Ampère's Rule.—Imagine yourself floating in the current within the wire, with your head in the direction in which the current flows and facing the needle. The north pole of the needle will always be on the left hand. A piece of soft iron lying in this position would be magnetized, with the polarity which would produce equilibrium according to Ampère's rule. This magnetic action of a current is utilized in all galvanometers.

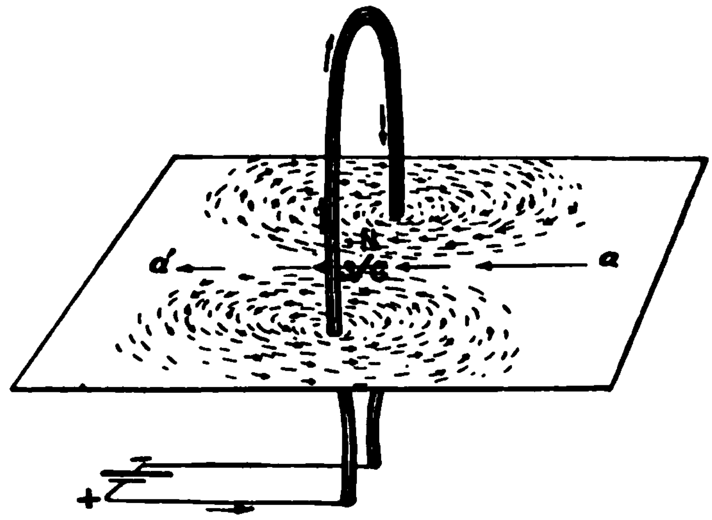

FIG. 372.—LINES OF FORCE WHEN THE WIRE IS BENT.

If the wire is bent into a circular form, as in Fig. 372, the lines of force revealed by iron-filings upon a glass plate are no longer concentric circles. Along the axis of the wire *a c a'*, the line of force is a straight line. A north pole placed on the right at *a* would move to *c*, then to *a'*, and then on to an infinite distance to the left along this line, if acted upon only by the current. All the other lines are closed curves encircling the wire. The arrows show the position of a magnet-needle.

In a galvanometer, the needle is hung at C. The coil is turned so that the needle, N S, is in the plane of the coil. When the current is turned on, the needle sets at such an angle that the forces of the earth and coil balance each other.

The Ampère-Meter.—Currents are measured by means of an Ampère-meter, of which one form is illustrated in Fig. 375. A short, lozenge-shaped needle, *n s*, is mounted on a small shaft, P, as shown in section (Fig. 373). The needle and shaft turn on a jeweled pivot, and are mounted between the poles of two strong curved magnets, M, which give direction to the needle, *n s*. The current is passed around two coils, C, of large wire, the size of which depends on the magnitude of the currents to be measured.

If the current in the coil should alone act on the needle,

the latter would turn 90° from the position shown in Fig. 373. If the current increases from zero, the needle will turn through a greater and greater angle. The motion of the needle is revealed by a pointer, I (Fig. 374), which moves over a scale graduated to ampères (Fig. 375).

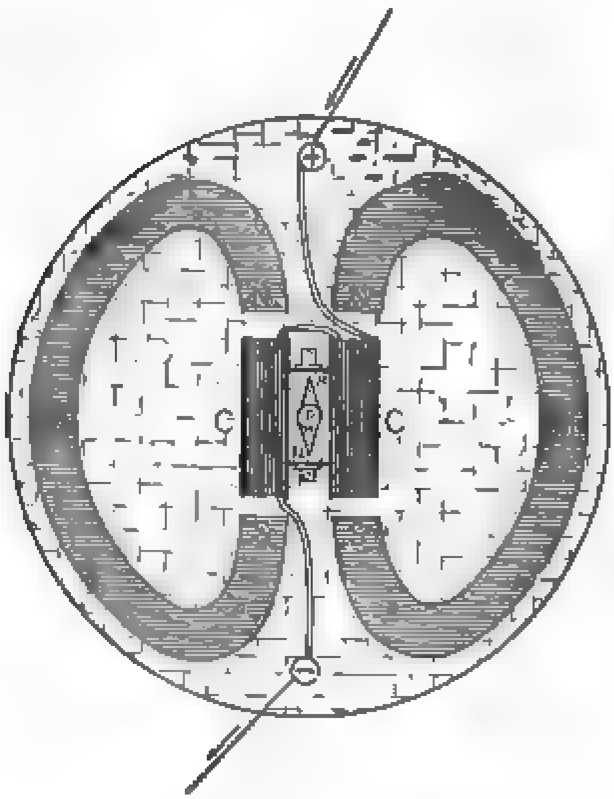

FIG. 373.—PLAN OF AMPÈRE-METER.

This scale is graduated as follows: Any temporary scale of equal divisions is placed under the index, I. The instrument is connected in circuit with a battery and a copper decomposing cell, the copper electrodes having first been weighed. As the battery may become weak, the current is kept constant by moving the plates nearer together, and thus diminishing the resistance. The plates should, therefore, clamp on a rod, so as to allow readily of such motion. The reading of the index, I, is thus to be kept constant.

If in 30 minutes it is found that 5·916 grammes of copper have been deposited, this would be at the rate of 11·833 grammes per hour. As one ampère deposits 1·1833 per hour, the current must have been 10 ampères. On the permanent scale, reading in ampères, this point should therefore be marked 10. Increase or diminish the current by changing the number of cells or by varying the resistance, and other points of the scale may be similarly determined.

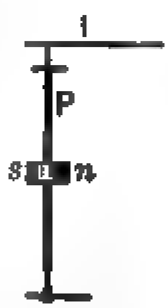

FIG. 374.

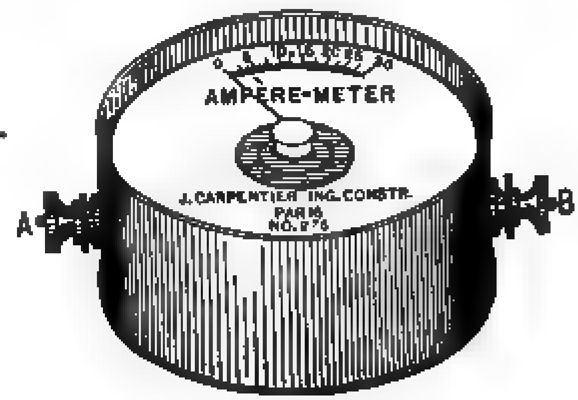

FIG. 375.—AMPÈRE-METER.

The Tangent Galvanometer, which may also be used to measure strong currents, consists of a coil of wire whose plane is vertical, and coincides with the plane of the magnetic meridian. At the center of the coil is a short magnetic needle, with a pointer attached, which plays around the graduated circle of a compass-box.

When no current is passing, the needle points to magnetic north and south. But, when a current is sent through the coil, it tends to deflect the needle at right angles to the coil. The strength of the current to a certain extent determines the amount of this deflection, which is always proportionate to the *tangent* of the angle of deflection. If the coil be turned 90°, so that the needle stands at right angles to it, and the current is then sent around in the proper direction, it will not affect the needle, which is already where the current tends to place it.

QUESTIONS.—What do you mean by the Ampère? How much copper will one ampère deposit in a second? How much silver in an hour? Explain how water may be decomposed by a current. What are electrodes? Distinguish by name positive and negative electrodes. Describe the relation between electrodes and battery-plates. Which current is feebler—that from electrodes or that from the battery? When the two are connected, what is the result?

How does the deflection of a magnetic needle furnish a ready method of detecting when and in what direction a current flows? State Ampère's rule for aiding the memory. Illustrate the application of this rule by holding the wire in various positions, above, below, parallel to the needle, etc. How do iron-filings arrange themselves on a glass plate through which passes a current-carrying wire? How, when the wire is bent into a circular form? Describe in detail the Ampère-Meter; the Tangent Galvanometer.

ELECTRO-MOTIVE FORCE.—THE VOLT.

By the Electro-motive Force of a Battery or cell, is meant its power of driving electricity through the resistance of the circuit. It is sometimes called electrical pressure. The unit electro-motive force, or difference of potential, is called the Volt. It is the electrical pressure required to maintain a current of an ampère through a resistance of an ohm.

The relation of current, resistance, and potential difference, can be illustrated by a current of water. In Fig. 376, T represents a tank of water, in which the water is maintained at a fixed level by means of a

pump, while the tank discharges through a pipe B *o*. At regular intervals glass tubes, serving as manometers (see page 198), are tapped into the discharge-tube. The height to which the water rises in each tube indicates the pressure. At the mouth of the main tube, the pressure is zero; it rises uniformly toward the tank.

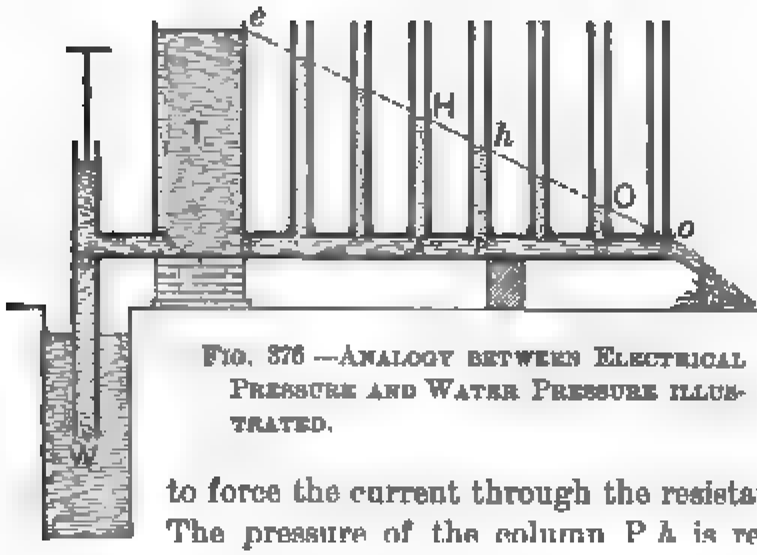

FIG. 376.—ANALOGY BETWEEN ELECTRICAL PRESSURE AND WATER PRESSURE ILLUSTRATED.

The current of water, in quarts per second, is the same in all parts of the tube. The pressure of the column of water, B *e*, is required to force the current through the resistance of the pipe C *o*. The pressure of the column P *h* is required to force the same current through the resistance P *o*. If P *o* is three times as great as C *o*, then P *h* must be three times as great as C O. From B to *o* the resistance is represented to be seven times as great as from C to *o*, and the pressure of B *e* is also seven times as great as C *o*.

The fall of pressure is the same through each unit of resistance. From A to P it is the difference between columns H and *h*. This difference in pressure is what is required to maintain the current through the resistance of A P, and it is the same as C O, or one seventh of B *e*.

If the pipe were half the section, the same pressure B *e* would deliver only half the current. The pressure line *e* H *h o* would, however, remain the same. If the discharge-pipe, on the other hand, were twice as long, the effect would also be to reduce the current to one half. Both of these changes would double the resistance of the discharge-pipe. To get the same current as before, the water in the tank would have to be raised to twice the height B *e*. The fall of pressure for each unit of resistance is thus seen to be always the same for the same current. All these statements are true for a current of electricity.

Electrometers are used for measuring potential or electric pressure. One form of the *quadrant electrometer* is shown in Fig. 377. Four insulated hollow quadrants of brass have suspended within them a flat hour-glass-shaped needle of aluminum. In Fig. 378 the quadrants are shown

as seen from above, and with the upper plates broken away to reveal the needle. Quadrants diagonally opposite are connected by wires. The needle hangs on a silk fiber, and connects below, by means of a platinum wire, with sulphuric acid, which forms the inner coating of a Leyden-jar, L, Fig. 377. The acid and needle are electrified by means of the Holtz machine, and in the best forms of electrometer there are devices for detecting and restoring leakage, so as to maintain a fixed charge on the jar and needle.


FIG. 377.—THE QUADRANT ELECTROMETER.

If the insulations are all clean and dry, the leakage will be very small. The needle sometimes has a small magnet attached to it, which gives it direction. It must be placed symmetrically with respect to the quadrants, as indicated.

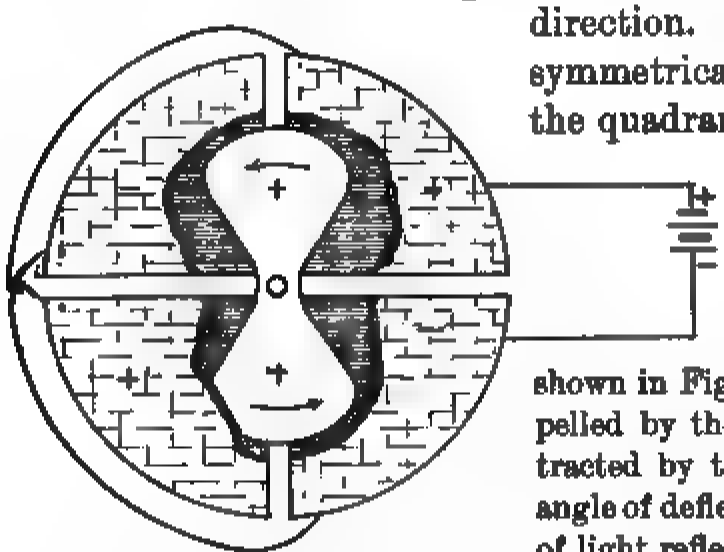
FIG. 378.—PRINCIPLE OF QUADRANT ELECTROMETER.

When the wires of a battery are connected with adjacent quadrants, they become charged, as shown in Fig. 378; the needle is repelled by the + quadrants and attracted by those charged —. The angle of deflection is read by a beam of light reflected from a mirror.

Adding cells in line, as in Fig. 359, increases the deflection. It increases the charge on the quadrants. It increases their electrical pressure or potential. It makes the + quadrants more strongly posi-

tive, and the − quadrants more strongly negative. If the space separating the quadrants is narrow, the pressure difference would become so great, by adding thousands of cells, that the charge would break through the insulation of air between the quadrants, a spark would pass, and the battery would maintain the discharge. We should practically have an electric light.

Adding cells in parallel, as in Fig. 360, does not change the potential. When cells are arranged in parallel-series, the deflection depends only on the number of cells in each line, and not upon the number of lines.

In Fig. 379, the line represented in Fig. 367 is shown in diagram. If one set of quadrants of the electrometer E be grounded, and the other connected with the line at A, the needle will be strongly deflected. If the contact is made

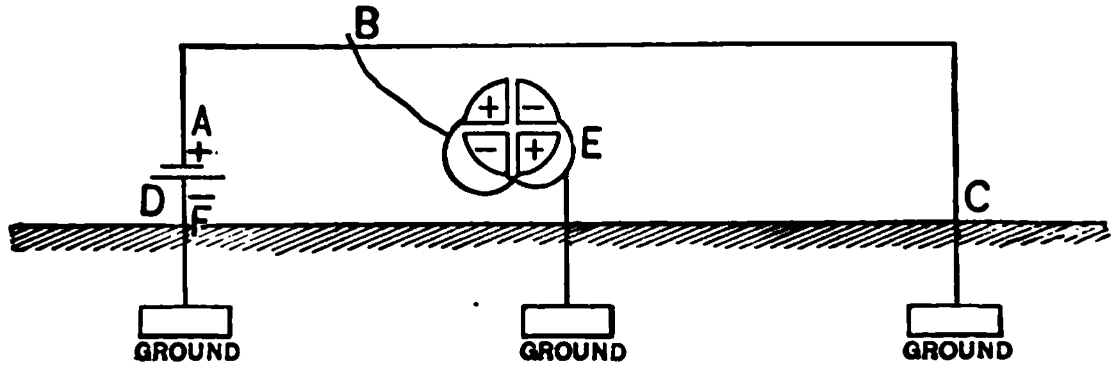

FIG. 379.—QUADRANT ELECTROMETER IN CONNECTION WITH TELEGRAPH LINE.

at B, the deflection will be less, and, as the contact slides to the ground at C, the deflection will fall to zero. Contact being made at D, the deflection will be in the opposite direction, but it will again fall to zero at F. The potential falls along the line A C, in the same way that the pressure falls in the pipe (Fig. 376).

If a battery of 1,500 Grove cells were connected in the line, it would be fatal for one to stand on the ground and touch the wire at A (Fig. 379). The human body would offer a rather high resistance, but the potential there is so much above that of the ground that a fatal current would be driven through the body. At B the danger would be less, and it would diminish to nothing at C.

Ohm's Law.—The relation of current, resistance, and potential, is expressed by Ohm's law.*

* The units ohm, ampère, and volt, were named in honor of the three great electricians—Ohm, Ampère, and Volta.

We have learned that one volt of electric pressure will maintain a current of one ampère through one ohm of resistance. Two volts will be required to maintain the same current through two ohms. R volts will drive an ampère through R ohms.

If we double the current through R ohms, we must double the pressure; hence—

2 R volts will drive two ampères through R ohms. Similarly, for any number of ampères, C.

C R volts will drive C ampères through R ohms. If E represents this number of volts, or the electro-motive force, then

$$E = C\,R, \text{ or } C = \frac{E}{R}.$$

This equation is an algebraic statement of Ohm's law. Expressed in words it is: The number of volts required to maintain a current of C ampères through R ohms is obtained by multiplying the number of units of current by the number of units of resistance.

The strength of the current C is directly proportional to the electro-motive force, and inversely proportional to the resistance.

If any two of the quantities in the equation for Ohm's law are found by measurement, the third can be computed.

Electro-motive Force of Cells.—In Fig. 376 the pressure of the column of water B *e* is required to overcome the resistance of the pipe B *o*. It is evident that the pump itself offers resistance to the passage of the current, and therefore that the total pressure required to drive the current through the entire circuit is really greater than B *e*.

This total pressure corresponds to the electro-motive force of a cell, or the electric pressure required to drive the current through the battery and external circuit. Such electro-motive force depends only on the materials used in the cell, and not at all upon its size. It changes somewhat as the liquids are exhausted during action.

The electro-motive force in the case of different cells is as follows:

Daniell gravity . . .	1·07 volts	Bunsen	1·94 volts
Grove	1·96 "	Leclanché	1·48 "

If 196 Daniell cells were connected into one line, the electro-motive force would be $196 \times 1{\cdot}07 = 209{\cdot}7$ volts. If 107 Grove cells were connected in line, the battery would have an electro-motive force of $107 \times 1{\cdot}96 = 209{\cdot}7$. If these batteries were connected against each other in one circuit, they would balance, and there would be no current in that circuit.

In the same way it can be shown that the electro-motive force of a battery is due simply to the cells in line. If 100 cells, all in parallel, be connected with one opposing cell, there will be a balance. The resistance of the battery of 100 cells will be the one hundredth of the resistance of one cell; but their electro-motive forces are the same. Similarly, two lines of 25 cells each, in parallel, will balance one line of 25 cells when connected in opposition in the same circuit. In the same way any number of pumps, working in parallel, would be balanced by a single pump of the same kind working against them in the discharge-pipe.

Divided Circuits.—When a battery-wire divides into two branches, as in Fig. 380, the current also divides between the two branches as a current of water would divide in a branching pipe. The sum of the two currents in the branches will be equal to the current in the undivided part. The fall of potential from a to b will be the same through the two wires, as the fall in pressure would be the same in the two branches of a tube. The pressure in the branches must be the same at the points where they unite.

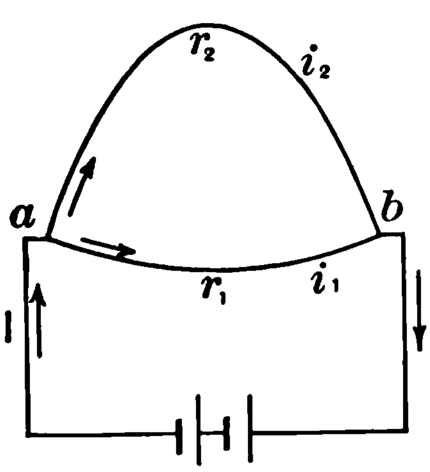

FIG. 380.—DIVIDED BATTERY-WIRE.

The currents in the branches are inversely as their resistances. The current will be least in the branch having the greatest resistance. If one branch be broken, its resistance will become infinite, and its current will be zero. If one resistance be practically zero, all the current will flow through it.

If the wire be looped (Fig. 381), and a good contact be made at *c*, no current will flow through the loop. It will flow directly across the joint at *c*. In a divided pipe (Fig. 382), where the resistance of one branch, A, is very small compared with that of the other, B, the former will carry all the current. In B there will be no appreciable flow.

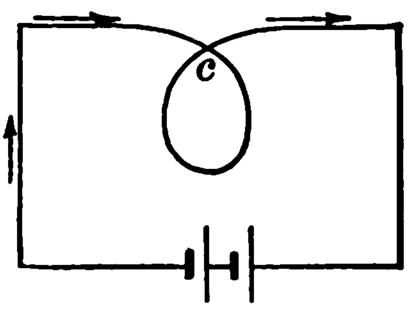

FIG. 381.
LOOPED WIRE.

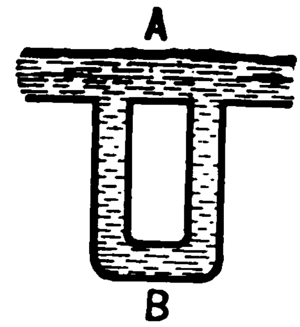

FIG. 382.
DIVIDED PIPE.

This condition is realized in a resistance-coil which has been plugged out of circuit. The current practically all flows through the plug instead of the coil. The resistance of the plug is practically zero. When the plug is drawn, the resistance of this branch becomes infinite, and the current is driven around the coil.

The same result would follow in the case of the pipe, if the short branch A were closed. The current would all flow around B, whose resistance would be introduced into the circuit.

Shunted Galvanometers.—When it is desirable to measure a current which exceeds the capacity of a galvanometer, a wire may be connected across the terminals of the galvanometer, and through it any fraction of the current may be deflected. This wire is called a *shunt*, and the galvanometer is said to be *shunted.* The galvanometer then measures a known fraction of the total current.

If the galvanometer have a resistance of 3·0 ohms and the shunt a resistance of $\frac{1}{9}$ of 3·0 or 0·33 ohm, then the current in the galvanometer will be $\frac{1}{9}$ of the current in the shunt, or $\frac{1}{10}$ of the total current.

Similarly, if the shunt have a resistance of $\frac{1}{99}$, the galvanometer resistance, only $\frac{1}{100}$ of the total current will be measured.

Shunt-wires should be doubled on themselves, like other resistance-coils, so that they do not become electro-magnets.

QUESTIONS.—Define the electro-motive force of a battery. By what other name is it sometimes known? Explain its relation to difference of potential. What is the unit electro-motive force, and by what name is it called? By what analogy may the relation of current, resistance, and potential difference, be illus-

trated? Draw a diagram on the blackboard to demonstrate that the fall of pressure for each unit of resistance is always the same for the same current.

Explain the use of the Quadrant Electrometer in measuring electric pressure. Illustrate the instrument by diagram. How might it become an electric light? Does adding cells in parallel change the potential? Under what circumstances would it be dangerous to touch the wire of an electric circuit? Why? Repeat Ohm's law. State it algebraically. To what is the current directly proportional? To what, inversely proportional?

Compare the total pressure required to drive a current of water through a pipe with the electro-motive force of a cell. On what does this electro-motive force wholly depend? Explain the balance of opposing batteries; of 100 cells in parallel and one opposing cell; of pumps working in parallel and a single opposing pump. Describe the division of a current; the current in the case of a looped wire; the passage of water through a divided pipe. What is meant by a shunted galvanometer, and for what is it used?

HEATING EFFECTS OF CURRENTS.

Heat developed by Resistance.—A short, thin wire of platinum, iron, or German silver, if placed in the circuit of a large Bunsen, Grove, or bichromate cell, will become red-hot. The remaining part of the circuit should be of short, thick wire. This is a case of the development of heat at a point of high resistance. The same thing, to a less degree, would happen in a short, narrow section of tube, in a water-pipe line through which water is forced, or at the door of a crowded audience-room when a panic occurs.

The short, thin wire has the same resistance as a larger one of much greater length. In the one case, the heat is generated in a small amount of material. In the large and long wire of the same resistance, the same heat will be liberated in a much greater amount of metal, and the rise in temperature will accordingly be less. The temperature rises until the heat generated in the wire each second equals the amount radiated. In the large wire the radiating surface per ohm of resistance is much greater than in the other.

Measurements show that a current of one ampère flowing through an ohm of resistance will yield 0·24 heat-unit a second; that is to say, each ohm of the wire will heat 0·24 gramme of water through 1° C. in

one second. If the current is doubled, the heat is four times as great, the heat liberated being proportional to the square of the current, thus:

1 ampère	through	1 ohm	yields	0·24	heat-units.
2 ampères	"	1 "	"	4 × 0·24	"
3 "	"	1 "	"	9 × 0·24	"
4 "	"	1 "	"	16 × 0·24	"

The amount of heat in two ohms will, in each case, be twice as great, and increases directly with the resistance.

The Calorimeter, shown in Fig. 383, is used for measuring the heat developed in a wire carrying a current.

The wire, R, is immersed in a badly conducting liquid contained in the vessel, C. Heavy refined coal-oil is generally used; alcohol or distilled water, however, will answer the purpose.

The current is measured by a galvanometer, and the difference in potential in volts on the two binding screws may be determined by means of an electrometer connected with them as before explained. The resistance can then be computed, and the amount of heat which should be liberated per second can easily be found.

The rise in temperature of the liquid is measured by a thermometer, T. A stirrer, S, is used to mix the liquid so as to secure a uniform temperature.

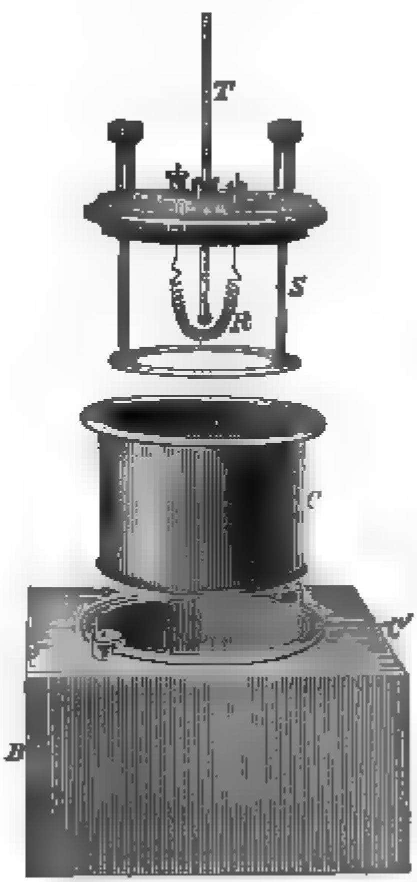

FIG. 383.—CALORIMETER FOR MEASURING HEAT IN CURRENT-CARRYING WIRE.

The calorimeter, C, is supported by its flanged lip, which rests upon a felt washer, C′. When in use, the calorimeter may be placed in a tin can, which is mounted in a box containing loosely packed sawdust. This is intended to prevent loss of heat by radiation.

The heat generated by the current is $0·24 \times C^2 \times R \times t$, in which C is the current in ampères, R the resistance of the coiled wire within

the liquid, and t the number of seconds the current is allowed to pass.

Problems.—The heat generated is also found from the rise in temperature of the liquid.

Suppose the stirrer and can to be of brass, to heat a gramme of which one degree C. requires 0·093 heat-unit. If they weigh 200 grammes, then for each degree of rise shown by the thermometer, $200 \times 0{\cdot}093 = 18{\cdot}6$ heat-units have been imparted to the can.

If the can contains w grammes of water, and the temperature rise through T degrees during t seconds, the heat given to the water is w T heat-units. The whole heat generated is T $18{\cdot}6 + w$ T heat-units.

These two quantities of heat must be equal to each other, or—

$$T18{\cdot}6 + wT = 0{\cdot}24C^2 \times Rt.$$

If the calorimeter contains 800 grammes of distilled water at a temperature 10° below that of the air, and is heated through 20°, the heat required will be

$$20 \times 18{\cdot}6 + 800 \times 20 = 16{,}372 \text{ units.}$$

If the resistance of the wire is 0·7 ohm at the air temperature, and a current of 10 ampères be passed through it, the heat liberated each second will be

$$0{\cdot}24 \times 100 \times 0{\cdot}7 = 16{\cdot}8.$$

The current, therefore, must run 974 seconds, or 16 *m.* 14 *sec.*, to furnish 16,372 heat-units.

Evidently if the amount of water, w, the rise in temperature, T, the current, C, the resistance, R, and the time, t, be all observed, the amount of heat imparted to the calorimeter (here 18·6 T) can be computed from the equation. It will be the difference between the heat generated by the current and the heat given to the water, or—

$$0{\cdot}24C^2Rt - wT.$$

Heat-Waste in Wires.—In all wires carrying currents, a part of the electrical power is wasted. A mile of pure copper wire having a diameter of 0·23 inch will have a resistance of one ohm.

The heat developed per second in such a wire when carrying a current of ten ampères, as is done in arc-light currents, will be

$$0{\cdot}24 \times 100 \times 1 = 24 \text{ heat-units.}$$

As one heat-unit (gramme-degree) is equivalent to 424·55 work-units (gramme-meter) (see page 269), this heat will be equivalent to

$24 \times 424{\cdot}55 = 10{,}189$ gramme-meters, or $10{\cdot}189$ kilogramme-meters per second. As one horse-power is 76 kilogramme-meters per second, the power lost in this mile of wire would be

$$\frac{10{\cdot}189}{76} = 0{\cdot}13 \text{ horse-power.}$$

The Watt.—Electrical power is also expressed in terms of Watts, one Watt being the power of a current of one ampère in a circuit of one ohm resistance.

The number of Watts in any case is the product of the number of volts and the number of ampères, or the product of the number of ohms and the square of the number of ampères. Since one Watt $= \frac{1}{746}$ horse-power, the horse-power is the number of Watts divided by 746.

QUESTIONS.—Explain the development of heat in a current-carrying wire. Suppose a current to flow through a wire which is thicker at one end than the other. If there is any difference in the strength of the current or in the temperature at the two ends of the wire, state the difference and explain it. How many heat-units will a current of one ampère flowing through an ohm of resistance generate in a second? If the current is doubled, how great is the heat? Describe a calorimeter used for measuring heat in current-carrying wires. Suppose the resistance of a wire to be $0{\cdot}7$ ohm and a current of 10 ampères to be passed through it, how much heat will be liberated each second?
Explain heat-waste in wires. How many heat-units are developed a second in a copper wire $\frac{33}{100}$ of an inch in diameter, when carrying a current of ten ampères? Convert this into work-units; into horse-powers; into Watts.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

How would you determine whether the electrification of a substance rubbed with a silk handkerchief is positive or negative?

A piece of copper wire 100 yards long weighs a pound; another piece of the same wire weighs a quarter. Show what are the relative resistances of the two.

Can the power of electrical attraction be developed in bodies in any other way than by friction?

After combing your hair on a dry day, why will little pieces of paper adhere for a few seconds to the comb?

Dip a piece of tourmaline into boiling water and apply it to your gold-leaf electroscope. Explain what happens as it cools.

Double up a piece of pasteboard and tear it across; either piece will cause the leaves to diverge. Why? *Because fracture as well as friction, etc., produces electricity.*

Explain why it is that if you walk rapidly over a carpeted floor on a clear, cold day, you can produce a spark on presenting your knuckle to any metallic object, or to the face or hand of a person who has just entered the room. See whether you can light the gas by means of this spark.

Why is dry air a good insulator? *Because it is a non-conductor; otherwise no body would remain electrified for an instant.*

Is a vacuum a good conductor of electricity?

Enumerate the fundamental facts of statical electricity.

Is it better to be wet or dry if exposed to a thunder-storm?

What parts of the house are most dangerous during such a storm?

Is the electrical discharge accompanied by any odor? Describe it.

A coil of wire having a resistance of 10 ohms, carries a current of 1·5 ampères. Required the difference of potential on its ends. *Ans.* 15 *volts.*

An electrometer connected on the terminals of an electric light shows a potential difference of 40 volts. The current through the lamp is 10 ampères. What is the resistance of the lamp and arc between the terminals? *Ans.* 4 *ohms.* How much heat will be developed in the lamp and arc each second? *Ans.* $0{\cdot}24 \times 10^2 \times 4 = 96$, *or enough to heat* 96 *grammes of water*, 1° *C.*

Has the velocity of electricity ever been measured?

The velocity of electricity depends upon the conditions. The actual velocity of propagation of electro-magnetic waves in space is the same as that of light, about 186,000 miles a second. The velocity of transmission of signals on telegraph lines is reduced very much by static capacity and self-induction. In one instance it was determined to be 16,000 miles a second between Washington and St. Louis; and in submarine cables it is between 7,000 and 8,000 miles a second.

Why are not birds on a telegraph wire killed by the passage of a current?

The current passing through a telegraph wire is not injurious to birds because it does not leave the wire; only an infinitesimal portion of it passes into the body of the bird. Should, however, a bird perched on a wire touch with any portion of its body a second wire during the passage of an electric current, the current might be deflected through the body of the bird with fatal consequences. Ingenious contrivances have been devised for killing mice and other small animals by making a connection through their bodies.

Do any animals present electric currents?

It has been observed that all living muscles are traversed by electric currents, which are more marked in the case of the warm-blooded animals, and are known to persist for a time after death.

Do any animals possess the power of giving an electric shock?

Certain fishes are provided with electric organs having the property of accumulating electric force and communicating it in shocks to other animals. Such are the electric rays, the electric cat-fish of the Nile, and the gymno'tus or electric eel, the latter the most powerful of all. The gymnotus inhabits the marshy regions of Brazil and Guiana, where it attains a length of five to six feet. It is an object of terror to the inhabitants, for the discharge of its batteries, which are planted on the back of the tail and along the anal fin, is fatal to the largest animals. Certain roads are said to have been abandoned in consequence of the number of horses annually killed, while crossing swampy depressions, by eels. The electric fishes employ their singular power both as a means of self-defense and to disable or kill their prey. In order that a shock may be communicated to the victim, it is necessary that the galvanic circuit should be completed by connection with the fish at two distinct points; painful sensations may be produced even by a discharge conveyed indirectly through the medium of water. The electric currents created at will in these animals have not been found to differ in their properties from those of the voltaic cell, in that they decompose chemical compounds, charge the Leyden-jar, render the needle magnetic, and even yield the spark. One surface of the electric organ is positive, the other negative. The power is exhausted after several discharges.

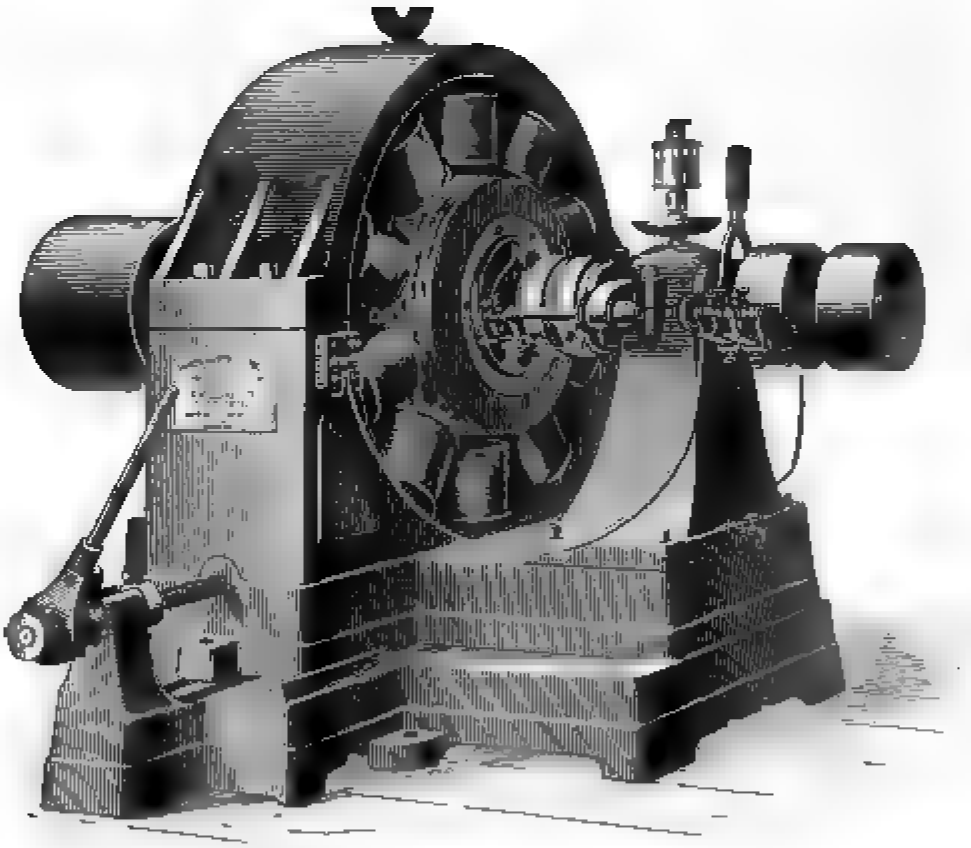

FIG. 384. ALTERNATING-CURRENT DYNAMO.

PRACTICAL APPLICATIONS OF ELECTRICITY.

GENERAL USEFUL EFFECTS.

Electricity has been applied to so many Useful Purposes that it has become one of the most important servants of mankind.

The Value of Electricity for Useful Work is entirely due to the fact that various effects can be produced by it with the greatest convenience, and such effects are usually more intense than those due to any other agency. The present useful effects of electricity are Magnetic, Inductive, Lighting, Heating, and Chemical. These are produced much better by electric currents, or dynamic electricity, than by frictional or static electricity, principally because the latter

gives only an instantaneous effect, like a spark, while the former will supply energy steadily for months at a time.

MAGNETIC EFFECTS OF ELECTRICITY, OR ELECTRO-MAGNETISM.

The Electro-Magnet.—We have already seen, in the case of the galvanometer, that a wire or coil, carrying a current near a needle, tends to make the needle deflect and take a position at right angles to the direction of the current; we have also learned that this effect is proportional to the number of turns of wire passing around the needle. This very important discovery of the action of an electrical current upon a magnetic needle was made by Oerstedt (*ör'sted*), of Copenhagen, in 1819. The experiment can easily be repeated by simply bringing near a compass-needle a wire connected with one or two cells of a battery.

If, instead of using a magnetic needle, we take a rod of soft wrought-iron, we shall find that it becomes magnetized when held at right angles to a wire carrying a current, although it possessed no magnetic properties beforehand. We find also that this effect can be intensified by increasing the number of turns of wire around the bar, and in this way we can make a magnet having all the properties of the permanent steel magnet. The magnetic action, however, is only temporary, and ceases almost entirely as soon as the wire carrying the current is removed, or the current stopped.

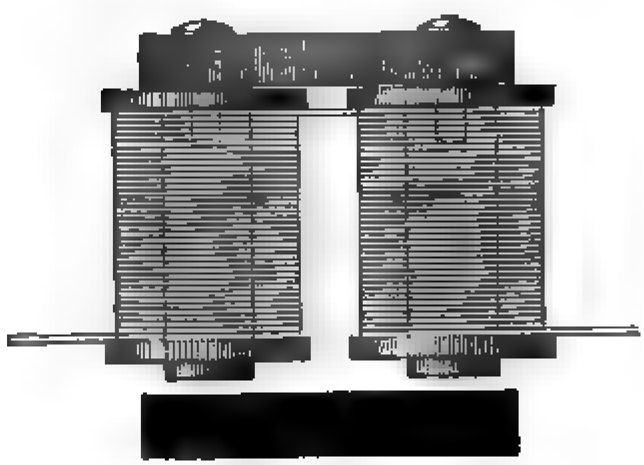

Fig. 385.—Electro-Magnet.

Such magnets are called electro-magnets, and usually consist of two wrought-iron cylindrical cores joined by a wrought-iron yoke, generally attached to the cores by screws, as shown in Fig. 385. Around

each core a number of turns of wire are wound, forming what are called the coils, spools, helices, or bobbins.

The coils should be wound or connected so that the current passes around one core in one direction, and around the other in the opposite direction, in order that one shall form a north pole and the other a south pole; and the rule is, that the current should flow around the north pole in a direction opposite to that of the hands of a watch, if we imagine the watch and the end of the core both to face us. A bar of soft iron is used as an armature, and is very powerfully attracted when a strong current is passed through the coils; but this magnetic effect continues only so long as the current flows, and the instant the circuit is broken the attraction ceases almost entirely. The slight effect which remains is called *residual magnetism*, and is similar to the retentivity or coercive force of permanent magnets. Since this residual magnetism is hardly perceptible in very soft wrought-iron, but is very strong in hard steel, and since a certain-sized electro-magnet of soft iron can be made to exert a much stronger attraction than one of steel, the softest and best quality of soft iron should, therefore, be used in the construction of electro-magnets.

A magnetic effect may be obtained from a coil of wire carrying a current, even though the coil has no iron core within it. Such a coil without a core is called a *solenoid*, and is sometimes used instead of an electro-magnet. The magnetic effect is, however, very much weaker if there be no iron core, the presence of iron tending greatly to concentrate and conduct the magnetic lines of force.

Electro-magnets are almost always used instead of permanent magnets, because their action is controllable and much more powerful.

The Practical Applications of Electro-Magnetism are many—in fact, electro-magnets form part of almost all useful electrical apparatus. The first of these applications that was developed is

The Electro-Magnetic Telegraph.—The simplest system of telegraphy, and the one most extensively used, is that invented in 1837 by S. F. B. Morse, an American. The Morse apparatus consists essentially of an electro-magnet, which, when a current passes through its coils, attracts an armature. In this way an operator can cause the armature to move, even at a distant station, by simply sending a current over a wire leading to that station.

The instrument by which the sending operator controls the current on the line is called a *key*, and is shown in Fig. 386. It consists simply of a platinum contact-point, mounted on a lever, which closes the electric circuit when the knob on the forward end of the lever is depressed. By means of this key, the operator sending the message can cause a current to flow over the wire through the receiving instrument at the other end, either for a short or long interval, and the motion of the armature of the distant receiving instrument will correspond exactly with that of the sending key.

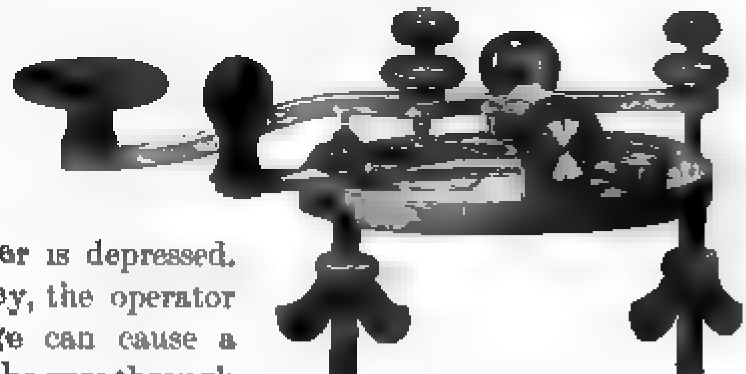

FIG. 386.—MORSE TELEGRAPH KEY.

The receiving instruments are of two kinds, the most common being the "sounder" (Fig. 387), which consists of an electro-magnet fixed vertically upon a flat base. The armature, which is a strip of soft iron, is mounted horizontally immediately above, but not touching, the poles

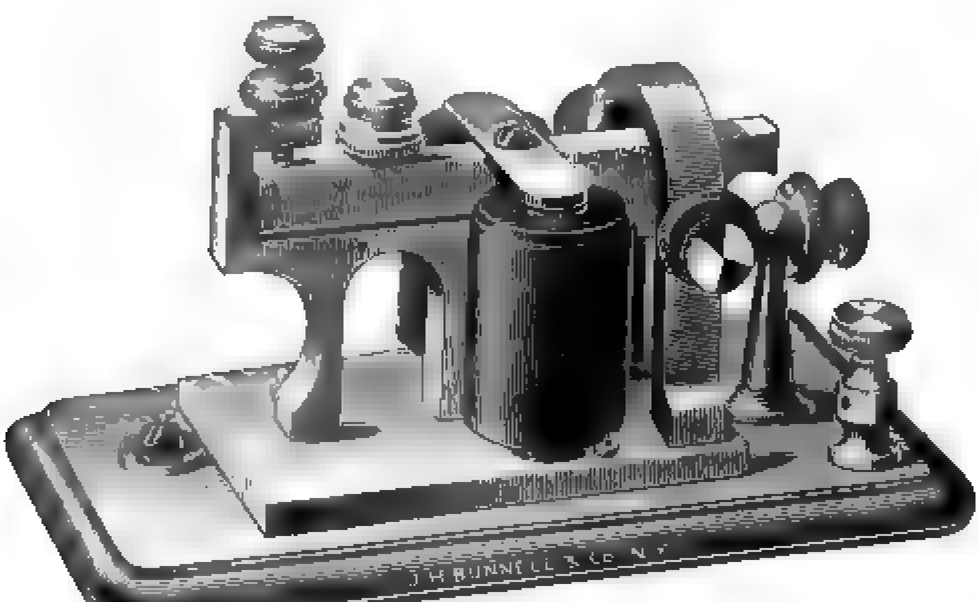

FIG 387.—TELEGRAPH SOUNDER.

of the magnet, and at the middle of a lever pivoted at one end. Screws are provided at the other end of the lever to regulate its up and down movements, and there is also an adjustable spring which always tends to draw the armature up.

When a current is passed through the magnet, the armature is drawn down, causing a click; and, when the current is stopped, the armature is pulled back by the spring, causing another click.

The other kind of receiving instrument is the register shown in Fig. 388. Here the armature causes marks to be made on tape, which is slowly moved by clock-work. If the current sent over the wire lasts only for an instant, a dot is impressed on the tape; but, if the current is continued, a dash appears. The marks are made on the tape either by simply indenting the paper with a sharp point or stylus on the end of the pivoted lever carrying the armature, or by means of some form of pen fed with ink.

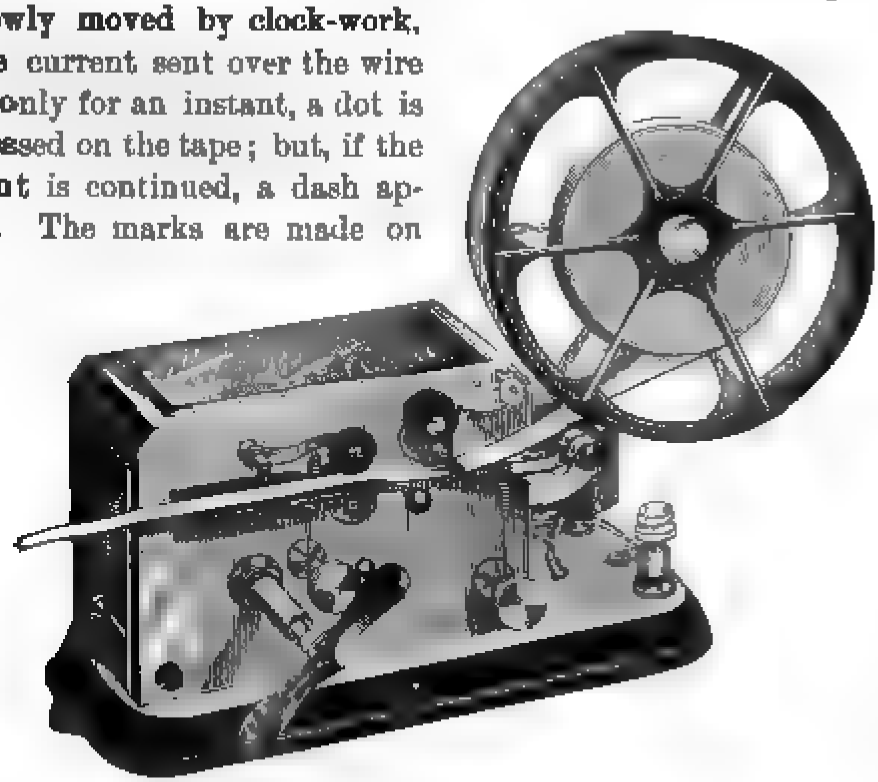

FIG. 388.—MORSE TELEGRAPH REGISTER.

The Alphabet, or Code of Signals, by which messages are sent, is composed of different combinations of dots and dashes—that is, short or long impulses of current over the line. The code used in this country, presented on the next page for reference, is the one originally devised by Professor Morse. The different signals are carefully selected, so that those used most frequently are the shortest. A slightly different code is employed in Europe. This was intended to be an improvement on the original Morse alphabet, but the European code has been found to require more time to send a given message.

MORSE CODE OF SIGNALS.

A · —	H · · · ·	O · ·	V · · · —
B — · · ·	I · ·	P · · · · ·	W · — —
C · · ·	J — · — ·	Q · · — ·	X · — · ·
D — · ·	K — · —	R · · ·	Y · · · ·
E ·	L ——	S · · ·	Z · · · ·
F · — ·	M — —	T —	& · · · ·
G — — ·	N — ·	U · · —	

NUMERALS.

1 · — — ·	3 · · · — ·	5 — — —	7 — — · ·	9 — · · —
2 · · — · ·	4 · · · · —	6 · · · · · ·	8 — · · · ·	0 ——

PUNCTUATION.

Period · · — — · ·	Interrogation — · · — ·	Paragraph — — — —
Comma · — · —	Exclamation — — — ·	Italics — · · —
Semicolon · — · · — ·	Parenthesis · — · · —	

It should be carefully noted that O differs from I in that the two dots are farther apart; L is twice, and the cipher three times, as long as T. C and R differ from S and from each other by being differently spaced. The same is true of H, Y, Z, etc. Skilled operators experience no difficulty in making these distinctions.

The Relay.—In the case of a long line, or where there are a number of instruments on one circuit, the current may

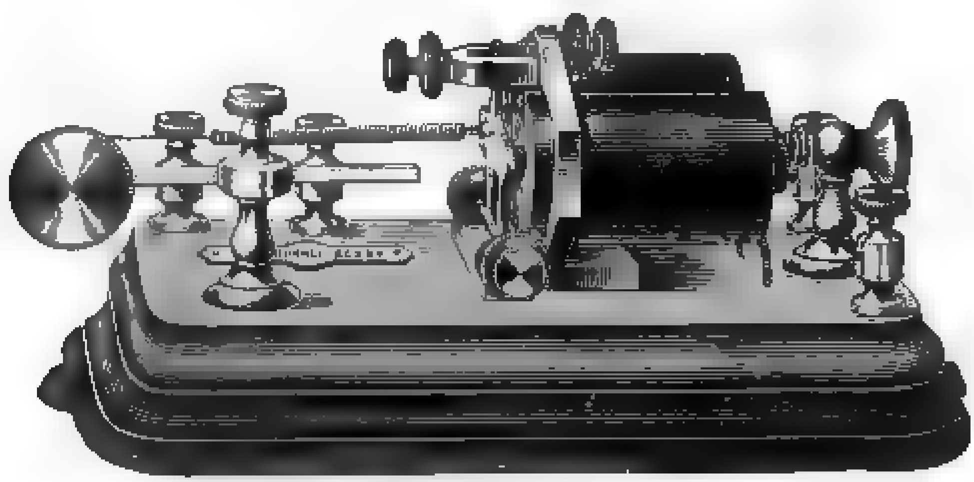

FIG. 389.—TELEGRAPH RELAY.

not have sufficient strength to work the receiving instruments directly; in such a case, a relay or repeater is used. The regular form of relay is shown in Fig. 389. It consists of an electro-magnet and pivoted lever carrying the armature, similar to the sounder; but in the relay a great many turns of very fine wire are used, in order to multiply the effect of

a weak current. The armature and lever are also made very light, so as to work easily; and a platinum contact-point, similar to that on the key, is mounted on the end of the lever, so that, when the armature is drawn forward, a local circuit, in which are included a local battery and the receiving sounder or register, is closed. The object of the relay is, therefore, to re-enforce with a strong local current any current too weak to do the required work itself.

The connections for the regular Morse circuit for one intermediate and two terminal stations are shown in the diagram (Fig. 390). If we trace out the connections in this diagram, we find that when the key K at the station A is depressed, it will send a current over the line

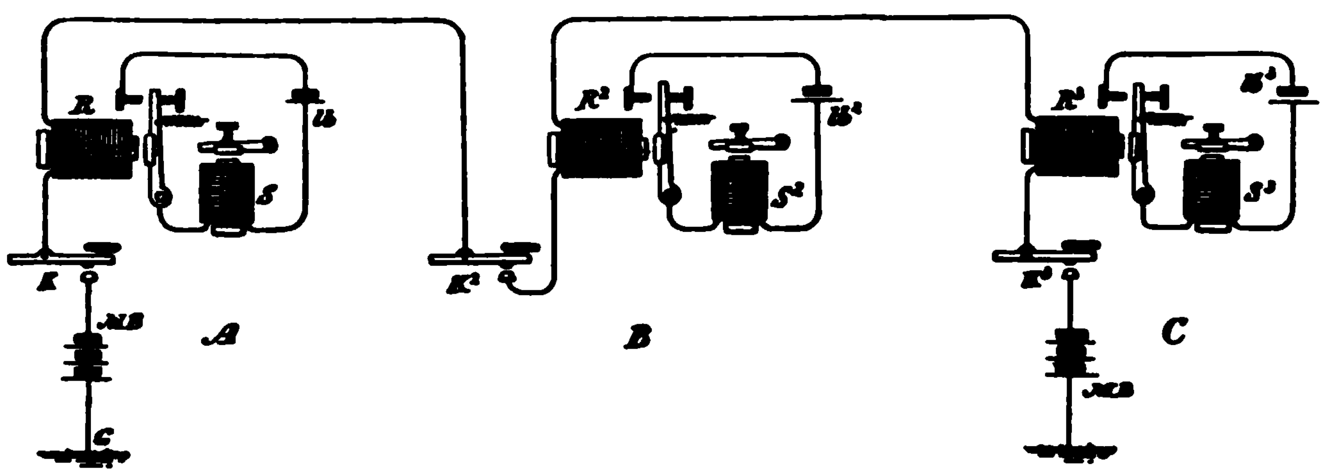

Fig. 390.—A Morse Telegraph Circuit.

from the main battery, M B, causing the armatures of all three of the relays, R, R^2, R^3, to be drawn forward. This will close the local circuit at each station, and the local batteries, *lb*, lb^2, lb^3, will cause the armatures of the three sounders, S, S^2, S^3, to move simultaneously in perfect correspondence with the motions of the sending key K. It will be noticed that the wire is carried to the plate G in the earth at each end of the line. By this means the earth is made to act as the return conductor to complete the circuit, and it is thus necessary to have only one wire, which effects a great saving on long lines. The keys are all kept closed except when used in telegraphing.

Faults may occur in Telegraph Lines from a number of causes: First, the wires may break, which, of course, entirely interrupts the signaling; secondly, the insulators may break or become imperfect, so that the current on the wire leaks off to the earth before it reaches the distant station, and thus weakens the effect; or, thirdly, two wires may

come in contact with each other and cause a mixing of the signals. This last fault is called a "cross."

Various methods for testing the existence and positions of faults are used by telegraph engineers. They usually depend upon accurate measurements of resistance or capacity (see page 485).

Duplex Telegraphy.—There are several methods of arranging telegraphic apparatus so as to transmit two mes-

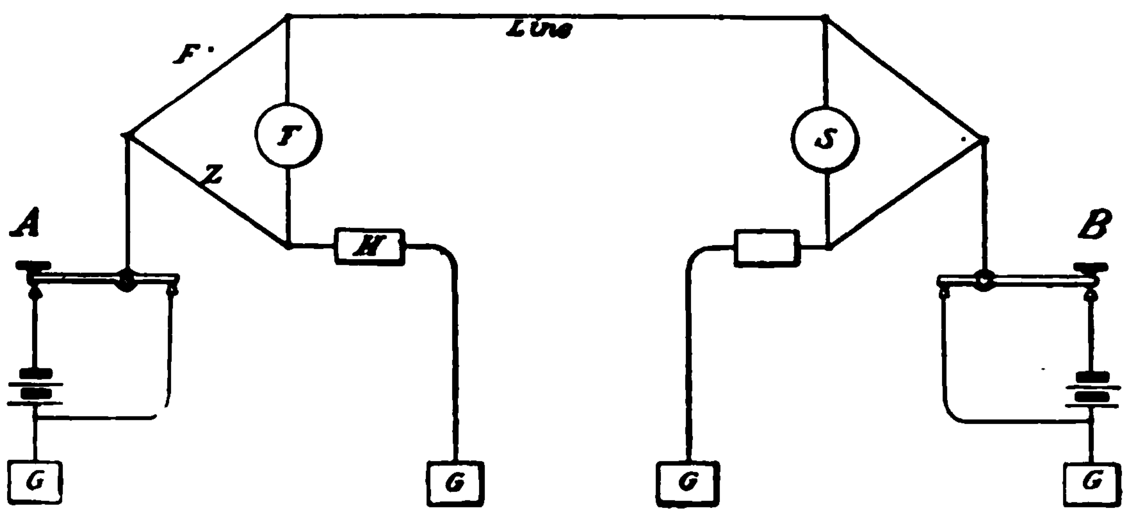

FIG. 391.—DUPLEX TELEGRAPH CIRCUIT.

sages through one wire at the same time. One of these methods of duplex working is called the Wheatstone Bridge method. Fig. 391 illustrates the principle. All that is necessary in a duplex system is that the receiving instrument at each end should move only in response to signals from the other end, so that an operator at A may cause the receiving instrument, S, to work without affecting his own receiving instrument, T. The same must be true from the other end also. In order to accomplish this, the circuit at each end is divided into two branches, one of which connects with the earth and the other with the line, and the receiving instrument is placed across between these branches.

Now, by the principle of the Wheatstone Bridge, if the resistance in F is to the resistance in Z as the resistance of the line is to the resistance of H, then no current will flow through the instrument when the key at A is closed; but if a current be sent from the other end, B, a portion of this current will flow through the receiving instrument, T, and cause it to work. In this way, signals can be sent at the same

time from both ends, which will operate the receiving instruments at the opposite ends of the line, but will not affect the instruments at the ends from which they are sent.

Multiplex Telegraphy.—By a further extension of the principle of duplex telegraphy, it is possible to send four messages on a wire at the same time, and some ingenious methods have been invented by means of which it is possible to send seventy-two distinct messages on the same wire at the same time; but, of course, such systems are extremely complicated, and practically useless.

Learner's Instruments.—A simple but complete telegraphic apparatus is shown in Fig. 392. Such instruments

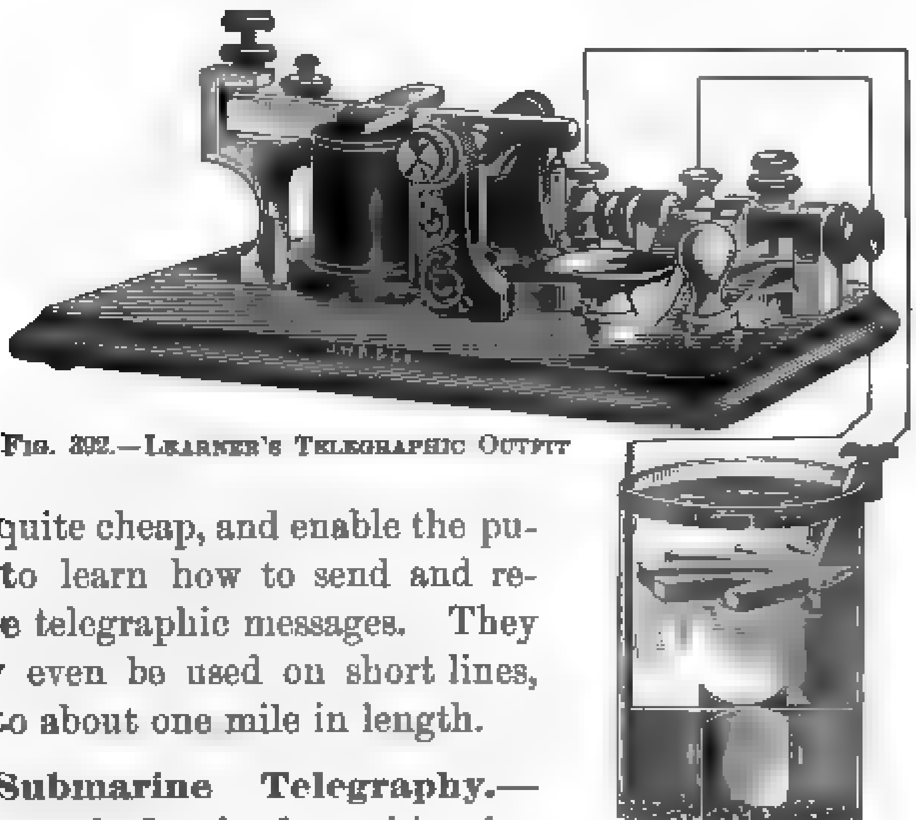

FIG. 392.—LEARNER'S TELEGRAPHIC OUTFIT

are quite cheap, and enable the pupil to learn how to send and receive telegraphic messages. They may even be used on short lines, up to about one mile in length.

Submarine Telegraphy.—The *methods of telegraphing* between places separated by water are very similar to those employed on land lines; but in the case of submarine telegraphy several serious difficulties are encountered, which make it necessary to use more nearly perfect lines and instruments. In the first place, if a telegraph wire is laid under water, it must be perfectly insulated throughout

its length with some non-conducting and water-proof covering; otherwise the current used in telegraphing would all leak off the wire in a very short distance. Submarine cables, therefore, consist of a core or conductor proper, made of several (usually seven) copper wires twisted together in order to be flexible. This core is covered, first with a stout layer of gutta-percha, then with a woven coating of jute, and finally with a sheathing or armor of ten iron wires, each covered with hemp. These are wound on the outside, and give the finished cable the appearance of a rope about one inch in diameter.

The strength of the cable depends upon this armor; and the breaks in cables, which so often occur and cause so much trouble and expense, are almost always due to the failure of this armor to stand the severe pull and scraping to which the cable is subjected.

Another serious difficulty in submarine telegraphy is the fact that a cable acts as an enormous Leyden-jar, which requires a large quantity of electricity to charge it. When a current is sent over the cable, the current has to fill the cable, as it were, before it can work the receiving instrument at the other end. This effect, which is called Static Induction, greatly reduces the speed of signaling through cables, so that not half as many words can be sent per minute as on ordinary land lines.

The existence of static induction also makes it necessary to use extremely sensitive instruments to receive the signals; in fact, it was for this purpose that Sir William Thomson devised his mirror galvanometer, which, we have seen, is also used in laboratories for measuring very weak currents. The motion of a spot of light reflected from the mirror enables the receiving operator to read the signals sent.

Electric Bells.—In many cases where it is not desired to send messages over a wire, but merely to make a sound to attract attention, electric bells are used. They consist of an electro-magnet and a pivoted lever carrying an armature similar to the sounder; but the lever is arranged to strike the bell when the armature is drawn forward, instead of merely striking the screw-point. In order to operate an electric bell, all that is necessary is to send a current through the coils of its electro-magnet. The usual means employed

for closing the circuit is a "push-button," which is merely a small spring contact-point.

The bell above described is what is known as a single-stroke bell, since it sounds but once each time the push-button is pressed. The continuous-ringing electric bell, which is the one generally used, because it has the advantage of keeping up the ringing as long as the button remains pressed down, is shown in Fig. 393. It differs from the bell already described in that the circuit passes through the lever which strikes the bell. When the armature is drawn forward, it breaks the circuit at the contact-point shown on the back of the armature. This allows the armature to drop back, after having struck the bell. The action is then repeated, causing a vibration and continuous ringing as long as the push-button is pressed.

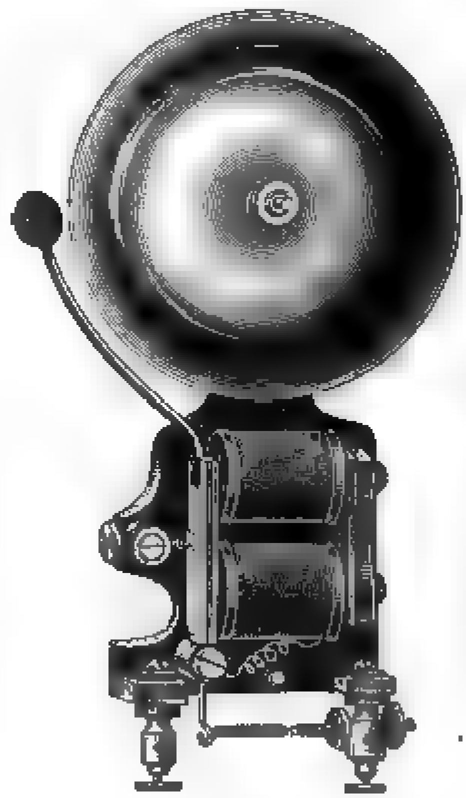
FIG. 393.—ELECTRIC BELL.

Such electric bells are used for many purposes, as door-bells, call-bells, and burglar-alarm bells. In the burglar-alarm, the push-button is replaced by a contact-point on the door or window, so arranged that when the door or window is opened, the circuit is closed and the bell rings. An attachment is often added by means of which the bell, once started by opening the window, will continue to ring after the window has been shut down again; otherwise, the ringing might not last long enough to give sufficient alarm.

Electric Clocks.—Another very similar application of electricity is the electric clock, the simplest form of which consists merely of one or two hands that are caused to move around by means of an electric magnet. The hands advance by what is called a "step-by-step motion" each time an electrical impulse is sent over the wire from the standard clock. The circuit is closed once every second. One *master-clock*, as it is called, may operate a number of electric

clocks placed around at different points on the same circuit It is in this way that standard time is sent over the country from the observatory at Washington or other important astronomical observatories.

QUESTIONS.—Explain the value of electricity for performing work. Enumerate the useful effects. Explain the principle of the Electro-magnet. What is a solenoid? Why are electro-magnets preferable to permanent magnets? Describe the Morse system of Telegraphy; the key, and its object; the sounder; the Morse telegraph register. Explain the relay, and state its object. Draw a diagram illustrating a Morse telegraph circuit.

How can two messages be transmitted through one wire at the same time? Explain the Wheatstone Bridge method. How may the principle of duplex telegraphy be extended? What difficulties are encountered in submarine telegraphy? Of what do submarine cables consist? Why are extremely sensitive instruments required to receive the signals? When was the first telegraph line built? *In 1844, between Baltimore and Washington.* How many miles of telegraph line are there now in the world? *Nearly* 800,000. The electric wire in operation in New York City alone is long enough to encircle the earth three times at the equator.

Describe the single-stroke Electric Bell; the continuous-ringing bell. For what purposes are electric bells used? What are Electric Clocks? Describe their method of operation.

INDUCTIVE EFFECTS OF ELECTRICITY.

Electro-Magnetic Induction.—We have already seen that a charge of electricity has the power to induce another charge in a body near it. This is called Electrostatic Induction. In the case of dynamic or current electricity, we also find that, when a magnet is moved near a wire, a current of electricity will be produced in the wire; or if an electro-magnet is suddenly excited by sending a current through its coils, a current will be produced in a wire or coil near the electro-magnet. In fact, any change whatever in the position or the strength of a magnet will tend to produce a current in a neighboring wire or coil.

The explanation of this phenomenon is usually expressed, according to the views of Faraday, by saying that the magnetic lines of force cut the wires or the wires cut the lines of force, which is the same thing. These lines of force are imaginary ones, which for convenience we assume to represent the magnetic force of attraction in

the neighborhood of a magnet. An idea of these lines has already been given in the case of the magnetic figures made of iron-filings (page 429). We have also seen that an electric current always has magnetic effects, and will turn a compass-needle. Therefore, when we move a coil carrying a current or vary the strength of the current in the wire, we shall produce a current by induction in the neighboring wire or coil. Thus we see that any magnetic change tends to produce an electric current in a wire in the neighborhood; but it must be borne in mind that a change of some kind is necessary. The mere presence of a magnet near a wire produces no effect whatever unless the magnet is moved or changed in strength.

It is possible to illustrate the above facts by very simple experiments. All that is necessary is to make a coil of insulated wire, say of 30 to 40 turns and two or three inches in diameter, the ends of which are connected with a galvanometer. A galvanometer may be improvised with a pocket compass, or a magnetized piece of knitting-needle suspended on a thread and surrounded by a coil of 30 or 40 turns of insulated wire. If a magnet is now thrust into the first coil or brought near it, the needle of the galvanometer will swing, showing that a current is generated in the coil. In fact, with a delicate galvanometer it will be very difficult to move either the coil or the magnet, even when they are a yard apart, without affecting the galvanometer-needle. If the magnet is replaced by a coil of wire connected with one or two cells of a battery, a similar set of experiments will show the induction currents made by the motion or variation of another current.

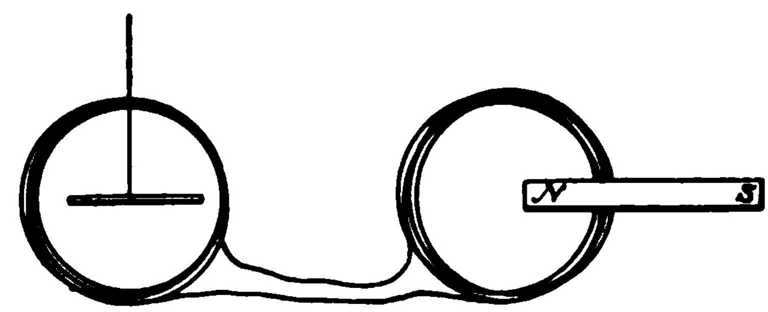

FIG. 394.—INDUCTION EXPERIMENT.

This electro-magnetic inductive action is of the utmost scientific and practical importance, since many of the useful applications of electricity are based directly upon it. For example, the dynamo-electric machine, the electric motor, and the telephone, are all apparatus for producing and using inductive action. The simple experiments suggested above will greatly aid the pupil in clearly understanding the principles of these machines, which are the three most important pieces of electrical apparatus.

The Induction Coil consists of an iron core surrounded by a coil usually made of three or four layers of coarse wire, the ends of which are brought out to binding-posts. Outside of this coil there is a second coil, usually consisting of a great many turns of fine wire; the ends of this coil are also led to binding-posts. The pupil may easily construct a coil of any desired size. The core should be made of a bundle of iron wire surrounded by stout paper and having square pieces of board about an inch thick at each end to hold the wire in place. The action of this coil is nothing more than the simple inductive action already described. When the current from a few cells of a battery is caused to pass through the coil of coarse wire called the *primary coil*, a current is produced in the *secondary* coil of fine wire, because the passage of the primary current makes the iron core strongly magnetic.

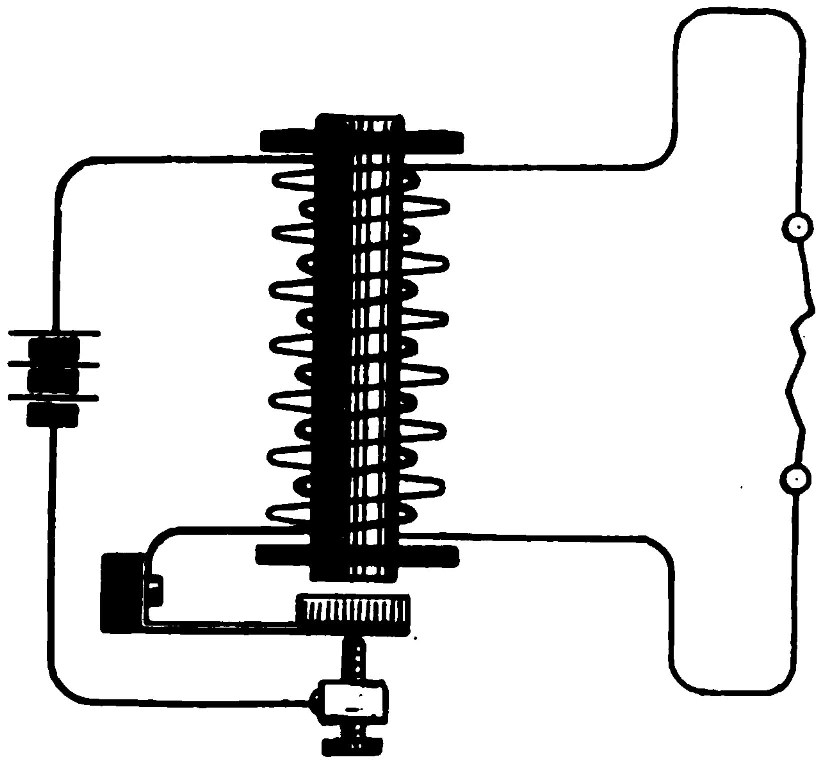

FIG. 395.—THE INDUCTION COIL.

Since this inductive action is exerted on each turn of wire in the secondary coil, it is evident that the total effect obtained from a large number of connected turns must be very marked, and this we find to be the fact. It is possible to obtain, from a comparatively small coil, sparks one quarter of an inch long when two or three cells are used on the primary circuit, whereas the cells alone would not be able to make a spark one thousandth of an inch in length. With a large induction coil we can increase the tension or jumping power to such an extent that we may cause the induced current to run round a theatre and light hundreds of gas-burners. Very large induction coils have been made with as many as 3,000 or 4,000 turns of wire in the secondary; some of them give a spark four or five feet long.

A spark is produced by an induction coil each time the primary circuit is closed or opened. The multiplication of effect is, however, only in the tension (designated as E. M. F., *electro-motive force*) of the current, and the actual energy in the secondary circuit can not be greater than that in the primary circuit. It will probably be considerably less, because of various losses. All we accomplish is to get a very much higher E. M. F. (measured in volts) than we have in the primary circuit, while the actual current of the secondary (measured in ampères) is much less than that of the primary. In short, we simply transform the electricity, and for many purposes this change of E. M. F. is desirable.

It is usual in induction coils, also called Ruhm'korff coils, to have some mechanical arrangement run by clock-work for opening and closing the primary circuit; or we may use an "electric buzzer," working on the same principle as the continuous-ringing electric bell, and applied to the end of the iron core of the induction coil.

The Telephone.—The transmission of speech by electricity is effected by means of an instrument called the Telephone, which depends entirely upon induction for its action. The ordinary Bell telephone, an extremely simple instrument, shown in section and in perspective in Fig. 396, consists of a magnet, M, having at one end a coil of very fine wire, S, and a sheet-iron diaphragm, G G, close to, but not in contact with, the magnet. These three parts—the magnet, coil, and diaphragm—are really all that is essential to the telephone. They are contained in a wooden case, F, having a mouth-piece, E. The connections from the two ends of the coil S are carried by two wires, C C, to two binding-posts, D D, at the other end of the instrument.

In order to use the telephone, we need simply connect two instruments in a complete electric circuit. Then, when we speak into the mouth-piece, the diaphragm will be made to vibrate by the sound, and its motion near the magnet, M, will cause variation in the lines of magnetic force, which we know will produce electric currents in the coil S. These currents will flow over the wires to the other telephone at

the opposite end of the line, where they will in turn change the strength of the magnet, causing the diaphragm of the second telephone to move in perfect unison with that of the first. Thus we see

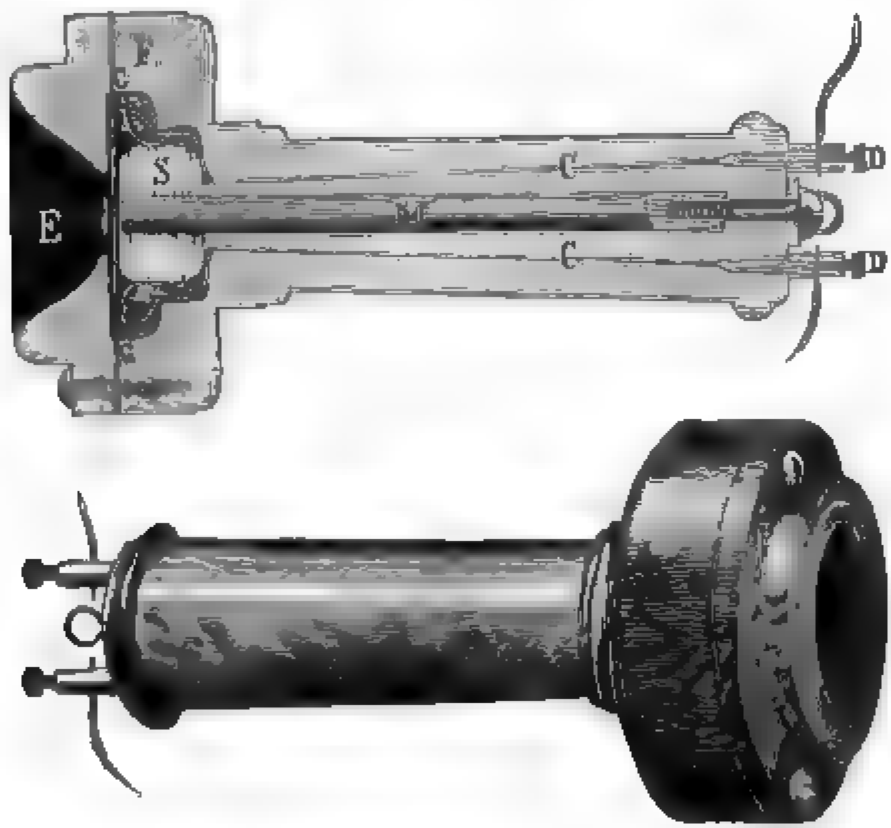

FIG. 396.—THE BELL TELEPHONE IN SECTION AND PERSPECTIVE.

that the sound-waves of the voice are turned into electrical waves in the first telephone, from which they travel over the wires to the second telephone, to be converted back into sound-waves. The action is so nearly perfect that it is possible to recognize a familiar voice. The Bell telephone may be employed in this way either as a "receiver" or "transmitter," but ordinarily it is used only for receiving.

The Usual Form of Transmitting Telephone is that invented by Edison and Blake. It consists simply of a carbon button in contact with a diaphragm, and a contact-point through which the electric circuit is carried.

When the diaphragm vibrates, it varies the pressure on the contact-point, changing the resistance to the passage of the current, and producing waves of current in the circuit corresponding to the vibrations of the diaphragm.

The connections for this kind of telephone are shown in Fig. 397, n which C is the carbon button mounted on a spring; D is the diaphragm; and F is the contact-point, placed between the two and in contact with both. The button is connected with the line wire which runs through the receiving instrument, R, and then to the earth, returning through the earth to the starting-point, where it passes through the battery, B, and back to the contact-point, C. This arrangement gives a stronger effect than two Bell telephones, but has the disadvantage of requiring a battery, whereas a Bell telephone used as a transmitter needs no battery, since it generates its own current by induction.

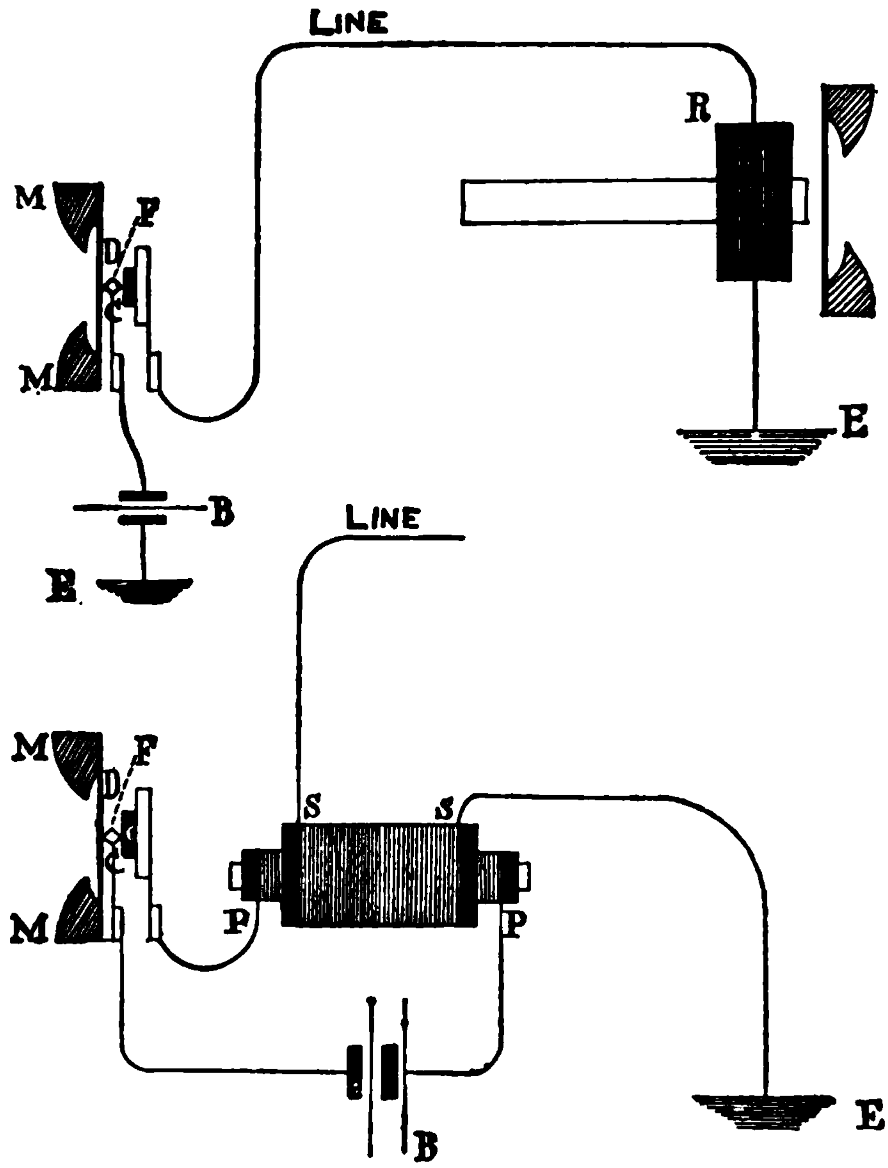

FIG. 397.—TELEPHONE CIRCUIT.

A still further application of the principle of induction is usually made in practice by passing the current from the transmitter through the primary P of an induction coil, as shown in the lower diagram of Fig. 397. The current obtained from the secondary coils, S S, is carried by the line wire to the receiving instrument at the other end. In this way, the E. M. F. of the current is raised so that the current is more easily carried over the wire, and the effect of the variable resistance of the contact-point is relatively greater than if no induction coil were added.

The electric bells commonly used with telephones are merely for signaling or calling up, and have nothing to do with the transmission of speech.

The Microphone is precisely the same in action as the transmitting telephone, it being really nothing more than a loose contact-point consisting of two pieces of carbon lightly

touching each other, and included in a circuit with one or two cells of a battery and a Bell telephone. The slightest vibration will jar the contact and vary its resistance, producing a sound. For instance, the ticking of a watch is distinctly heard, and even the footfalls of an insect under favorable conditions will produce vibration enough to make a sound in the telephone.

The Dynamo-Electric Machine is the most important of all electrical apparatus, as it is the generator or source from which ninety-nine per cent of all the electricity now used is obtained. It is practically necessary for any one who wishes to employ a considerable amount of electricity, for any purpose, either to have a dynamo on the spot, or else to bring the electricity over a wire from some supply-station where dynamos are kept running. In the experiment illustrating electro-magnetic induction, it was shown that, when a wire is moved in the neighborhood of a magnet, an electric current is generated in the wire. This is the essential principle of the dynamo-machine—in fact, a wire caused to move near a magnet is an elementary form of dynamo.

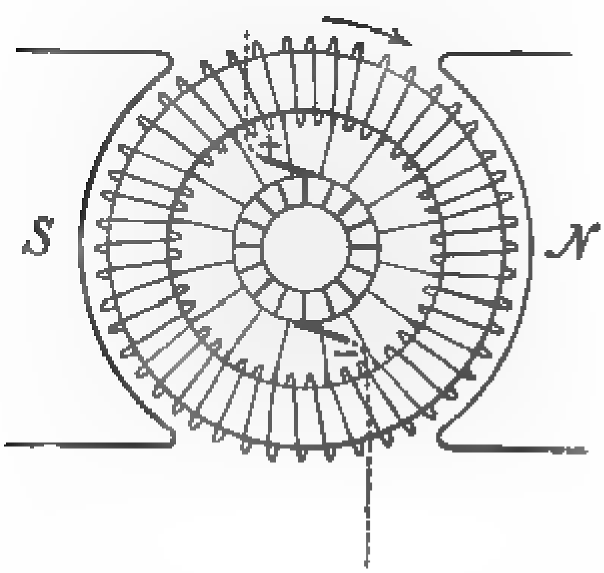

FIG 308.—THE GRAMME RING ARMATURE.

The power of the current obtained by this inductive action depends: 1. Upon the strength of the magnet; 2. Upon the length or number of turns of wire, 3. Upon the speed of the motion; 4. Upon the conductivity of the wire. The particular means used to secure these conditions are different in each machine, and hundreds of different forms have been invented. The common dynamo, however, is

simply a coil or series of coils of wire, known as the armature, revolving between the poles of a powerful electro-magnet, called the "field magnet," which produces the magnetic field in which the armature revolves.

The Gramme Ring.—There are two principal types of armature used in dynamos. The first is called (from the name of its French inventor) the Gramme Ring, and consists of a ring of iron wound around with wire, which virtually forms one endless coil. Connections are made with this coil at various points, each of which is in communication with a number of insulated copper bars, made into a cylinder called the "commutator." Now suppose this ring armature to revolve between the poles of a magnet; then one side of the ring will be acted upon by the north pole and the other side by the south pole, and currents will be produced in the wire in one direction on one side of the ring, and in the opposite direction on the other. These currents will meet in the middle, either at the top or bottom of the ring, if the poles of the field magnet are on each side. If two conducting brushes are placed in contact with the upper and lower points of the commutator, respectively, the currents produced in the two sides of the ring will unite and flow out of one brush through any circuit which may be provided, and back to the armature through the other brush. This action is kept up so long as the armature revolves, and a continuous current of electricity is obtained.

The object of the commutator and brushes is to make sliding contact with the armature, which revolves at a high speed, and also to obtain a continuous current by causing the coils under the influence of the north pole, and those under the influence of the south pole of the field magnet, always to be connected with the circuit in the same way, and therefore to produce a continuous current.

The Siemens Armature.—Another important form of armature is the Siemens Drum Armature, which consists of a drum or cylinder of iron wound longitudinally with a

number of sections of insulated copper wire, forming one endless coil. Each section is wound in a different direction or plane, and is connected with one bar of the commutator.

FIG. 399. WINDING AN ARMATURE.

The workmen are applying the insulated copper wire lengthwise around the armature-core. The ends of the section in which the wire is wound are seen projecting at the left. These ends are subsequently attached to the sections of the commutator; and insulated binding-wire, of poorly conducting German silver, is wound round the cylinder in successive bands to hold the coils in place.

The action of this armature is practically the same as that of the Gramme ring; one half of the coils generate a cur-

rent in one direction and the other half in the opposite direction, the two currents being united to the circuit and taken off by the brushes. The Edison dynamo-machine has an armature of the Siemens or drum type, and its field magnet is a massive horseshoe.

In the first electrical generators, the field magnets were permanent magnets, and the machines were called magneto-electric generators; but in 1867, Siemens and Wheatstone independently conceived the idea of using the current generated by the machine itself to excite the electro-magnets which formed the field magnet. This great invention was thought at the time to be most remarkable, since it appeared to imply a principle similar to that of a man attempting to lift himself by his own boot-straps. But, as a matter of fact, there is no reason why a machine should not feed its own field magnet, since the current required for this purpose is rarely more than five per cent, and is sometimes as low as one per cent, of the total current produced by the machine. The only difficulty is that there must be some magnetism to start with, or the machine will not "excite" or "build up." There is usually, however, sufficient residual magnetism to generate a little current; this strengthens the magnetism, which in turn produces more current, and so on, till the full strength is reached.

The Alternating-Current Dynamo.—The machines so far considered produce direct currents—that is, currents which always flow in the same direction, and which result from the use of the commutator, as described. If, however, the ends of the coil of wire forming the armature are connected with two copper rings on the shaft, and brushes are kept in contact with these rings when the armature revolves, then an alternating current will be produced, because the coil will first pass the north pole and then the south pole, producing a current first in one direction, then in the other.

This kind of current is called an alternating current, and its importance and extensive use are due to the fact that, by means of a transformer, which is merely an induction coil, the E. M. F. of this current may be raised or lowered as desired. Hence, it is possible to send a current of high E. M. F. over a comparatively small wire, and, where it enters a building, to reduce the E. M. F. to a safe point, by a transformer, thus saving the cost of a large wire. It is impossible to trans-

form a continuous current in this way, as we have seen that a steady current has no inductive effect. An alternating-current dynamo, capable of running a thousand incandescent lamps, is shown on page 505.

Uses of Dynamos.—During the last few years, thousands of dynamos have been built and put in use for a great

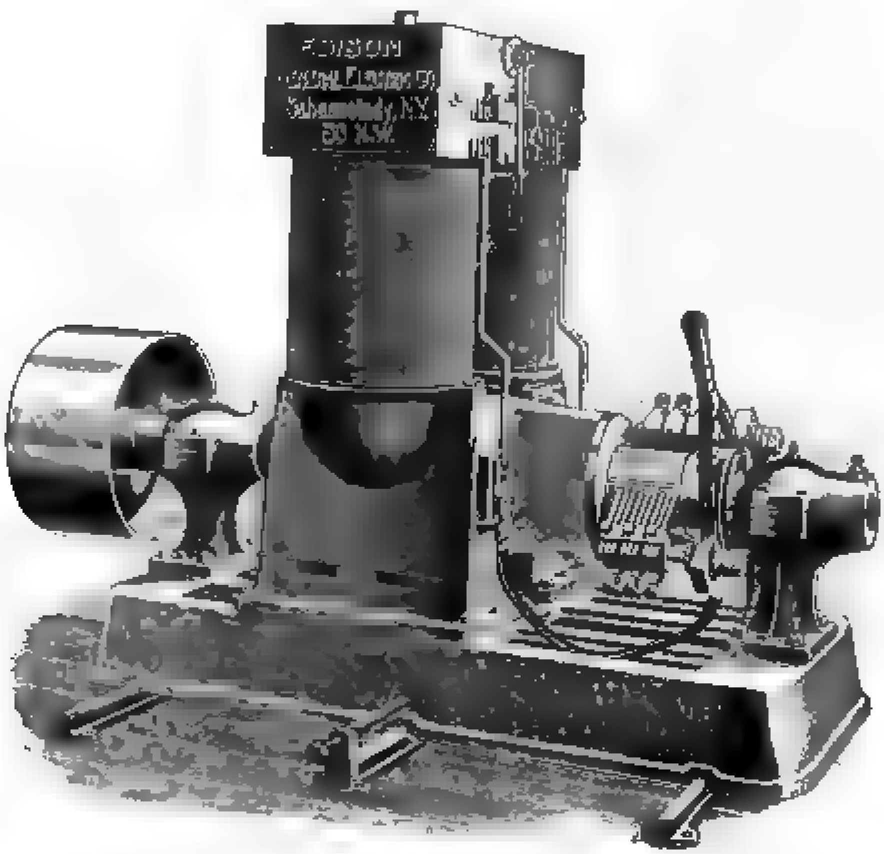

FIG. 400. THE EDISON DYNAMO.

many different purposes. They are employed to generate electric currents for electric lighting, electro-plating, motive power, telegraphy, charging storage-batteries, electric welding, etc. The medical electrical machines, which turn by a handle, are virtually small dynamos.

The advantages of the dynamo are twofold: First, a comparatively small machine will produce a powerful current (for instance, a machine weighing twelve hundred pounds—the weight of a large horse—will easily generate fifteen horse-power of electrical energy); secondly, the efficiency of the dynamo is remarkably high, there being machines in

practical use capable of generating electric power to the extent of over ninety per cent of the mechanical power applied to them. The mistake should not be made, however, of supposing that the dynamo runs itself, or that very little power will run it. Mechanical power of some kind must be applied to the shaft in order to turn the armature, and the result obtained in electric current is directly proportional, and nearly equal, to the mechanical power applied. Only two kinds of machines are commonly used for running dynamos—the steam-engine and the water-wheel.

Electric Motors.—We have seen that, when the armature of the dynamo is revolved, a current is generated; this action can be reversed, and a current sent through the armature which will cause it to revolve. The principle here is the same as that involved in the production of a current in a wire moved near a magnet, and conversely, in the motion of a current-carrying wire near a magnet. The same machine can be used either as a dynamo or a motor, a good dynamo being a good motor; but ordinarily, for practical reasons, motors are made slightly different from dynamos.

Electric motors are used for many purposes, the most important of the applications being to ventilating-fans, pumps, printing-presses, lathes, drilling-machines, circular and band saws, sewing-machines, grindstones, etc. The great advantages of electric motors are that they occupy little space, they require little or no skill to run them, and they are economical, for the reason that they need be operated only when required, as the current can be turned on or off instantly.

Transmission of Electrical Energy.—The dynamo is a machine for transforming the mechanical energy of a steam-engine or water-wheel into electric energy, while the electric motor transforms the energy of the electric current into mechanical energy. It is obvious, therefore, that we may run a dynamo with a steam-engine or water-wheel at a certain place, and carry the current produced by the dynamo over a conducting wire to an electric motor at some other place where work is to be performed.

The transmission of energy in this way has three great advantages: First, the electricity can be carried a great distance (even as far as thirty or forty miles); second, it is possible to run a great many small motors for different purposes from one circuit, so that the power generated at one central station by large steam-engines or water-wheels can be distributed to hundreds of different motors scattered through a manufacturing town; and third, the electrical energy can be transmitted over a very small conductor, a wire one fourth of an inch in diameter being capable of transmitting twenty-five horse-power at 220 volts, which is a perfectly safe E. M. F.

Electrical Railways.—The most important illustration of the transmission of electrical energy is the electric railway. The commonest and most successful electric railway system consists of a central generating station having a number of large dynamos, usually run by steam-engines. From this station, the current generated is carried by copper wires along the line of the railway, usually immediately over the middle of the track and about fifteen feet high. The current is taken off this conducting wire by an arm attached to the top of the car and having a trolley at the end, which runs along and makes continuous contact with the wire. This current is carried to an electric motor placed underneath the car and connected with the axle. When the man running the car wishes to move forward, he simply closes the circuit with a switch and allows the current to flow through the motor, thus causing the motor and car-wheels to revolve. In order to cause the car to move backward, the current through the motor is reversed.

Instead of running street-cars by this overhead-wire system, storage-batteries placed directly upon the car itself are sometimes employed to furnish the current for the motor. This plan has an advantage in that the car carries its own supply of electricity, and therefore requires no wire leading along the track. The disadvantage of the system is the great weight of the batteries, which amounts to several thousand pounds. The storage-battery used for this purpose will be described later (see page 535).

QUESTIONS.—Illustrate Electro-magnetic Induction. How is the phenomenon explained? Can you suggest an experiment which will throw further light upon the principle? Show how electro-magnetic inductive action is applied. Explain the construction of the Induction Coil. State fully the principle involved. Give an idea of the power and uses of the induced current. What is gained by this transformation of electricity?

What purpose does the Telephone serve? Explain the principle of the ordinary Bell Telephone; illustrate by diagram. Of what does the usual form of transmitting telephone consist? Draw a diagram illustrating the details of a telephone circuit. Describe the Microphone.

State the importance of the Dynamo-Electric Machine, and the principle of its construction. Upon what does the power of the current obtained by means of this machine depend? What is essentially the common dynamo? Describe the Gramme ring; the Siemens armature. How is the current generated by the machine itself utilized to excite the electro-magnets? Describe the Alternating-Current Dynamo, and state its advantages. What are the uses of dynamos? What kind of machines are employed for running them? Explain the principle of Electric Motors. For what are they used, and what are their advantages? How is electrical energy transmitted? Describe two methods of running street-cars by electricity.

HEATING AND LIGHTING EFFECTS OF ELECTRICITY.

Production and Control of Heating Effect.—If a strong current of electricity is passed through a small wire, the wire will become heated; if the strength of the current be increased, its temperature will rise until it becomes red-hot, then white-hot, and finally the wire may even melt or vaporize. It is difficult to get great heating effects from a small number of cells; but two or three cells of a bichromate of potash battery, particularly if connected in parallel, will give a sufficient current to heat a fine copper wire or an iron wire red-hot. The thinner the wire and the shorter its length, the easier it is heated. The principles and quantitative facts in regard to the heating effects of currents have been fully described on page 500.

The currents from dynamo-machines are strong enough to melt wire, although it is dangerous to use them for this purpose, as it puts a sudden strain upon the machine and is also liable to melt the wires with which the armature is wound. Large dynamo-machines have been made capable of giving a current strong enough to melt a solid bar of copper as thick as a man's wrist.

The most important application of this heating effect is the electric lamp, which is merely a device for producing it with sufficient intensity and steadiness to give a practical light. There are two kinds of electric lamps, the arc and the incandescent or glow lamp.

Arc Lamps.—If the terminals of two wires leading from a powerful battery or dynamo be brought together, and then separated about an eighth or sixteenth of an inch, the current will continue to flow across the space between the ends of the wires, producing a light of dazzling brilliancy. This light is due to the intense heating effect of the current caused by the resistance at the point where it flows across. The ends of the wires are raised to a white-heat of sufficient intensity to melt any known substance, including even platinum and the diamond.

FIG. 401.—THE ELECTRIC ARC.

As terminals made of metal rapidly melt, pencils of carbon, which is the most infusible of substances, are used for this purpose. Two carbon rods with the current passing between them are shown in Fig. 401. It will be noticed that the path of the current is in the form of an arc, from which fact the arc lamp and voltaic arc take their names. Even carbon is slowly vaporized and burned away in the electric arc; therefore, to make the light steady, it is necessary to have some way of feeding the carbons as they burn. This is accomplished by clockwork mechanism, which feeds the carbons together as fast as they are consumed; or by means of a mechanical clutch arrangement, which allows the upper carbon to drop a little by its own weight when the distance between the carbons becomes too great. A regular form of arc lamp is shown in Fig. 402.

The Incandescent Lamp consists of a thin conductor, which is made nearly white-hot by the current. Platinum

wire was first used for this purpose, but it was found liable to melt; thin strips or filaments of carbon were therefore substituted in incandescent lamps.

The filament of the Edison lamp is carbonized bamboo; but carbonized thread and even hair have been employed for this purpose. The use of carbon makes it absolutely necessary to remove all the air from around the filament, otherwise it would be burned up as soon as it became red-hot. Hence, the filaments are inclosed in a glass bulb, from which the air is pumped with a mercury air-pump; the bulb is then hermetically sealed. The air-pump used is so effective that only one-millionth part of the air is left in the bulb.

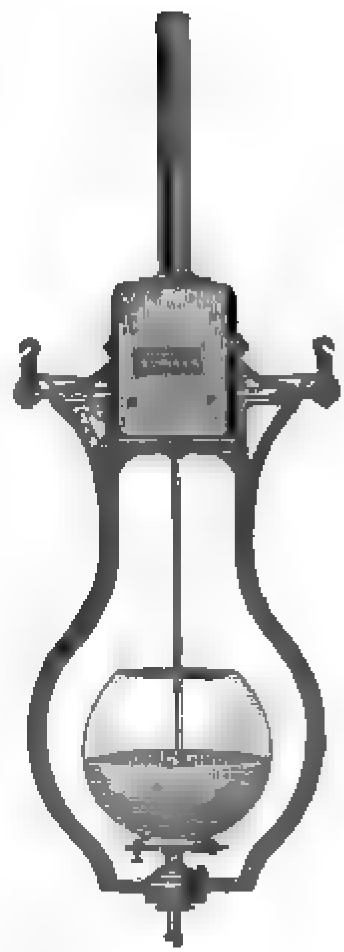

FIG. 402.—THE ARC LAMP.

The construction of the Edison lamp is shown in Fig. 403, in which G is the glass bulb, L is the loop or filament of carbon, E E are platinum wires connected with the ends of the filaments and leading through the glass, one of which is connected with the brass ring, B, and the other with the brass button, D, at the bottom of the lamp. When the lamp is screwed into the socket that holds it, this ring and button are in contact with brass pieces in the socket, which in turn are connected with the wires supplying the current.

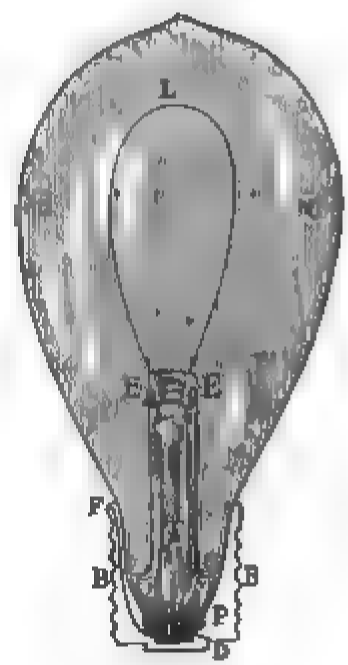

FIG. 403.—EDISON INCANDESCENT LAMP.

An electric lighting plant consists of one or more dynamos for generating the current, switches for controlling the current, wires for carrying the current to the places where it is to be used, and lamps for converting the current into light.

The two kinds of lamps are connected with the circuit in entirely different ways. Arc lamps are connected in series—that is,

the current flows through one, then the next, and so on—whereas the incandescent lamps are connected in parallel—that is, the current divides or branches into a number of parts, each of which flows through a single lamp. The chief advantage of arc lamps is their great power and comparative economy of current. Thus it costs only two or three cents an hour to produce a light of six or eight hundred candle-power; and only a single small wire is required, which may be run for six or eight miles, with the lamps attached wherever desired. Arc lighting is suited to large spaces, such as streets and parks. The advantages of incandescent lighting are that the light is more distributed and not so intense at one point, and that it is very much more steady than the arc light—in fact, it is among the steadiest artificial lights known.

The electric light has been used in capturing deep-sea fishes two miles below the surface; it is proposed to employ it in photographic apparatus for the purpose of making negatives of the ocean-bottom.

Danger in Electric Lighting.—Arc lamps, being almost always run in series, require a high E. M. F., usually from 1,000 to 3,000 volts. Incandescent lamps, on the other hand, being almost always run in parallel, require only from 50 to 120 volts. The principle of this difference has been illustrated by pumps on page 478. It therefore follows that touching an arc circuit is usually much more dangerous than contact with an incandescent circuit, the effect on any animal being directly proportional to the E. M. F., other things being equal. The danger limit is between 300 and 500 volts; below this the effect may be disagreeable, but is not serious. All danger is obviated by perfect insulation and avoidance of actual contact.

Electric Welding.—There are other applications of the heating effect of electricity besides electric lighting. The most important and most recently developed of these is electric welding. The art consists simply in placing together the two pieces of metal to be welded, and passing a very powerful electric current through the juncture. This heats the surfaces of the metal in contact to such an extent that they fuse together and make a perfectly solid joint. The convenience and effectiveness of electric welding are

remarkable. Only the surfaces of the two metals are heated; therefore the amount of heat required is very small, and the metals are not made black and dirty as they would be if placed in a fire. It is also possible in this way to weld brass and copper to iron and steel. Heretofore, welding had been confined to iron and steel; now it is possible to weld electrically almost any two metals.

The ordinary form of electric welding apparatus consists of two sliding clamps for holding the metals to be welded. These are connected with a dynamo-machine specially made to give a current of several thousand ampères. When the metals are brought in contact, the current flows across the joint and fuses them together. The current is then stopped and the joint solidifies.

Electric Furnaces.—Electricity has been used in a somewhat similar manner for reducing metallic ores, melting metals, etc. The electric furnace or crucible for this purpose is provided with two electrodes or conductors, usually heavy plates of carbon, between which the material to be treated is placed. When a powerful current is passed between the electrodes, the material is intensely heated.

Electricity has even been used for Cooking Purposes, the heat being produced by passing a strong current through conductors which offer resistance to its passage. For example, if a coil of wire be placed in a vessel of water, and a strong current be passed through it, the water will become sufficiently heated to boil an egg.

CHEMICAL EFFECTS OF ELECTRICITY.

Electro-Plating.—When an electric current is passed through any liquid which is a conductor, a chemical effect is usually produced in the liquid. In the case of a solution of some metal, the latter will be deposited on the cathode, as already described (page 488).

The article to be plated is connected with the negative pole of the battery or dynamo, and a piece of the metal for plating is connected

with the positive pole. This arrangement is shown in Fig. 404, where A is a silver anode connected with the positive wire, and C is a spoon to be plated, connected with the negative wire. A resistance switch, S, is inserted into the circuit to regulate the strength of the current. The anode and cathode are hung in a bath consisting of a solution of silver, and as soon as the current is caused to pass between the anode and the spoon, the solution will be de-

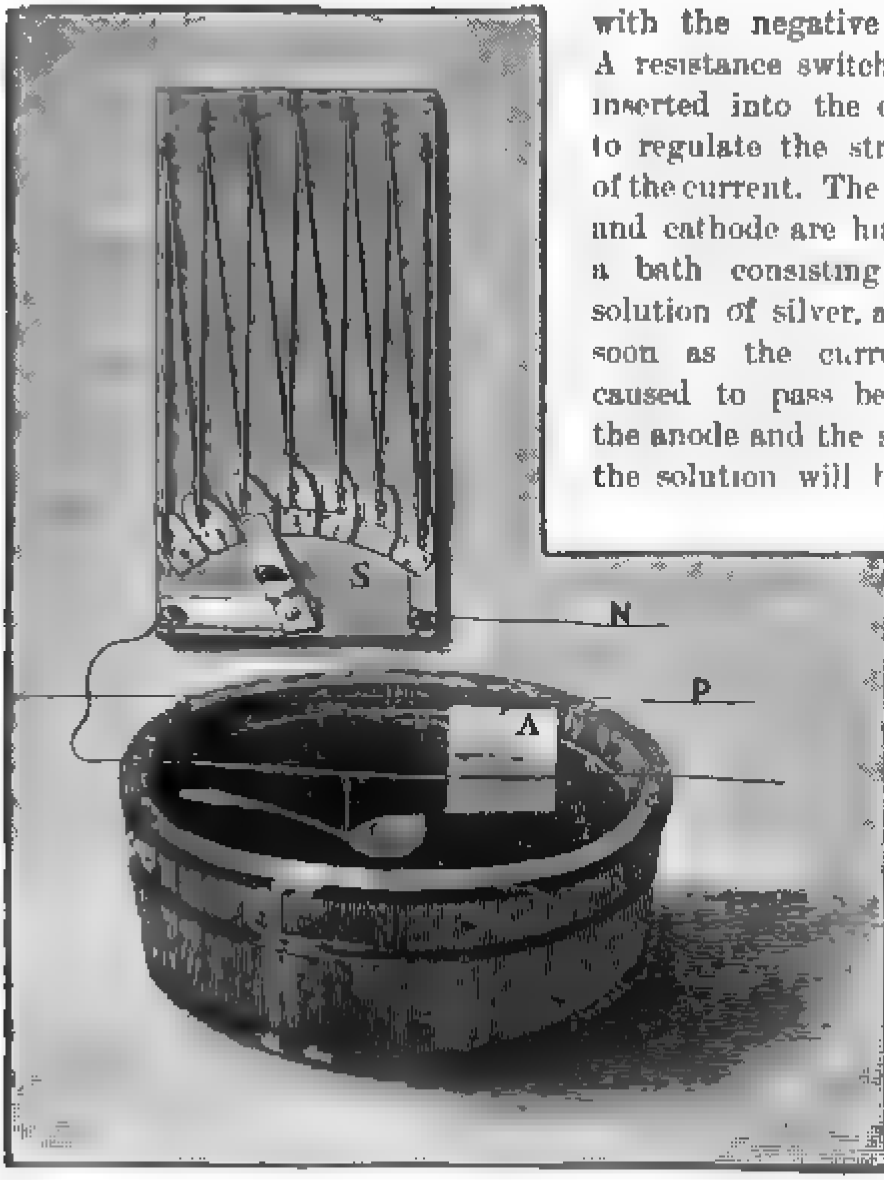

FIG. 404.—ELECTRO-PLATING APPARATUS.

composed and the silver will be deposited on the spoon, the thickness of the coating depending upon the strength of the current and the length of time it passes.

Secondary, or Storage-Batteries.—The principle of Storage-Batteries is very similar to that of electro-plating. The batteries are made up of plates of lead (the electrodes), or an alloy of lead, cast in the form of a "grid," or frame-

work of bars crossing one another at right angles, as shown in Fig. 405. The holes in the plate are filled with a paste of lead oxide. For the positive plates, the paste is made of red lead and sulphuric acid; while for the negative plates, litharge and sulphuric acid are used.

The positive and negative plates are placed alternately in a bundle (Fig. 406). They are kept apart by strips of rubber and bound by strips of wood dovetailed together. The plates are supported on wooden blocks, which in turn rest upon the bottom of the glass jar. The negative plates of one cell are all connected in parallel at one end of the cell by means of their connecting strips. The positive plates are connected at the other end. The manner of connecting the cells is shown in Fig. 407. The liquid surrounding the plates is dilute sulphuric acid.

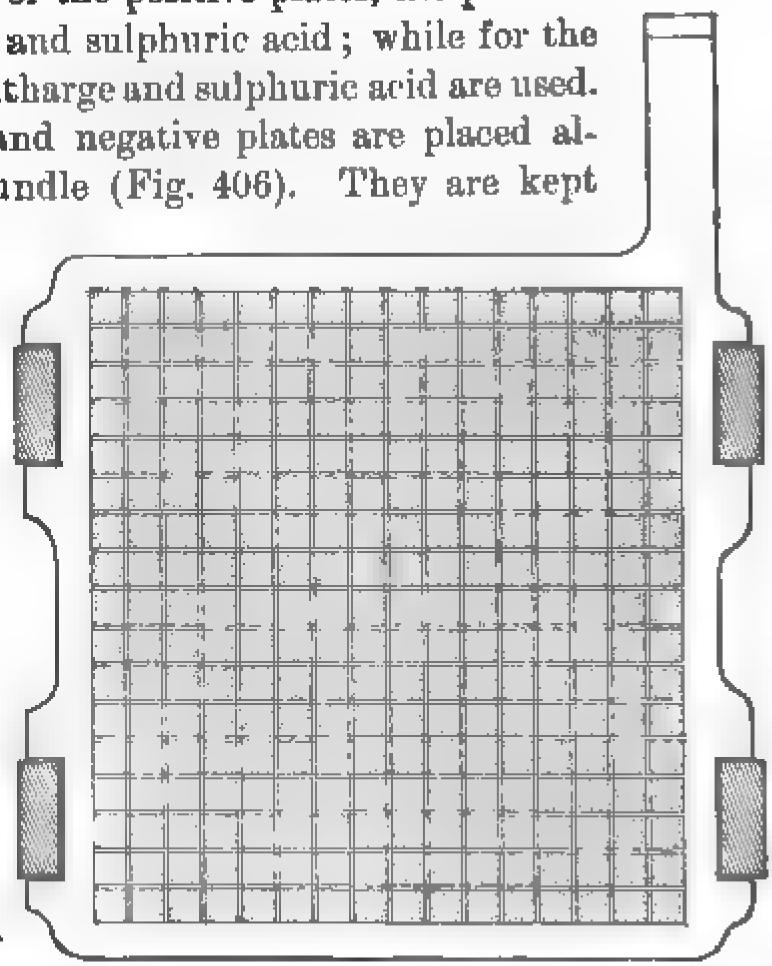

FIG. 405.—STORAGE-BATTERY: THE GRID.

When the battery has been exhausted, it is charged by connecting a dynamo with the terminals of the battery, and sending a current through it. This current reverses the chemical action, which goes on during the discharge of the battery. As already stated, the plating-vat behaves in a similar manner.

Storage-batteries have an electro-motive force of 2·2 volts per cell. The resistance per cell depends on the size and number of plates composing each cell; it is usually 0·005 ohm, or less.

The main difficulties with such cells are that the paste drops out of the holes in the lead plates, and the plates finally warp or buckle and come in contact with one another within the liquid, thus making a short circuit which discharges the cell.

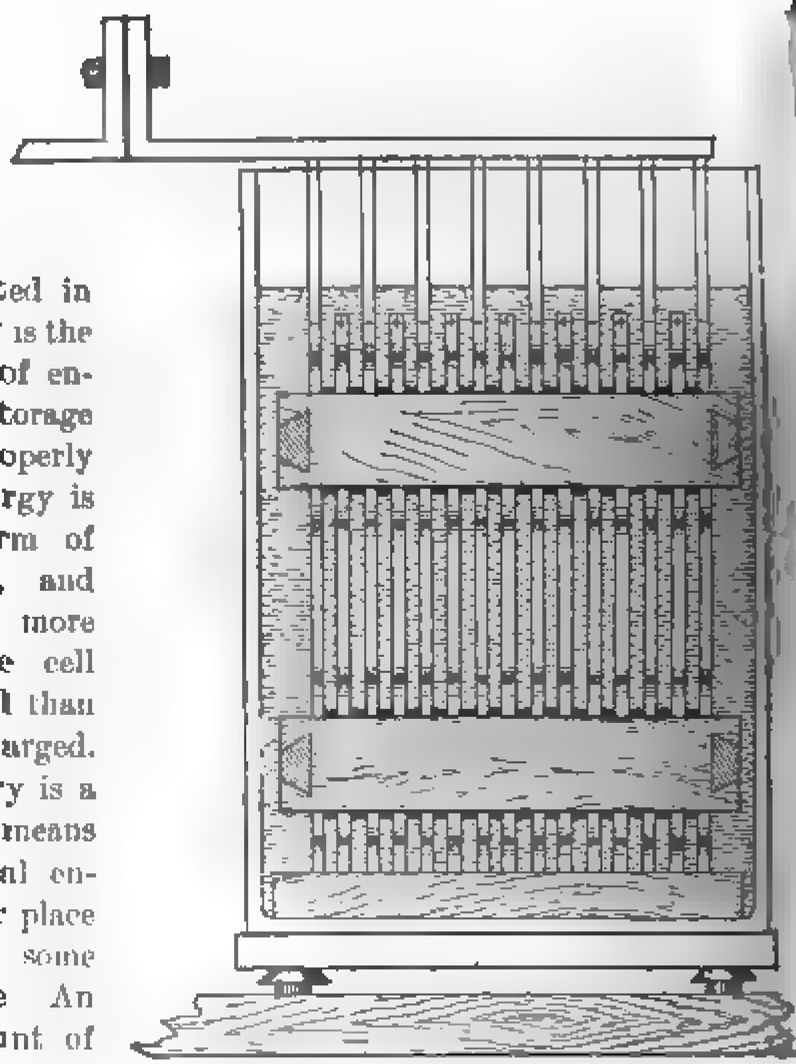

FIG. 406.—ARRANGEMENT OF POSITIVE AND NEGATIVE PLATES.

What is effected in the storage-battery is the electrical storage of energy, not the storage of electricity. Properly speaking, the energy is put into the form of chemical affinity, and there is really no more electricity in the cell when it is charged than after it is discharged. The storage-battery is a very convenient means of taking electrical energy at one time or place and using it at some other time or place. An idea of the amount of storage-battery required for any given purpose may be obtained from the statement that a battery capable of giving one horse-power for five hours weighs 500 pounds, or, in other words, it will supply twelve incandescent lamps of sixteen candle-power each for five hours; but then it will have to be recharged by the current from a dynamo.

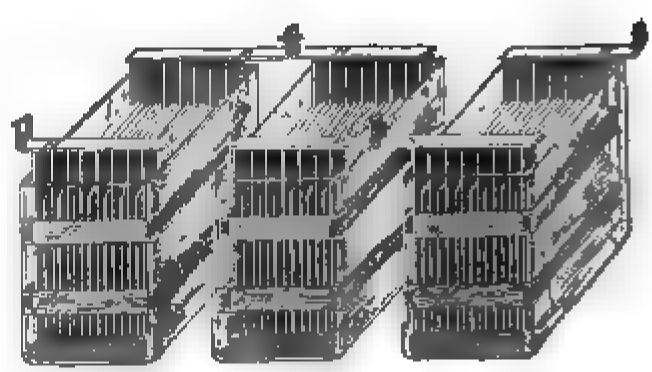

FIG. 407.—METHOD OF CONNECTING CELLS.

ELECTRICITY IN WARFARE.

Electricity on Ships-of-War.—One of the most important and extensive applications of electricity is to military and naval operations. The electric search-light, which is merely a very powerful arc lamp with a reflector, may be effectively used on a ship-of-war at night to enable her to

FIG. 406.—SHIP-OF-WAR USING HER SEARCH-LIGHTS.

enter harbors, avoid obstructions, detect the presence of hostile vessels, torpedo-boats, floating torpedoes, etc. A number of electric motors are often employed on a man-of-war to drive ventilating-fans, manipulate the heavy guns, hoist and set in place the enormous cartridges, revolve the turrets, etc. Electric signals also place in communication different parts of the vessel.

Electricity has been employed in land warfare for field telegraphing, exploding mines and torpedoes, illuminating magazines, where the use of any other artificial light would be perilous, etc. The velocity of cannon-balls is now accurately measured through the agency of electricity.

ELECTRICITY IN MEDICINE AND SURGERY.

The Uses of Electricity in Medical Practice are many and varied. Applied to the muscles or nerves, it may tell us of the presence of disorder; and, where derangement is found to exist, it may restore the functions of the organs involved, as in cases of curable paralysis and wasting of the muscles. The sudden change of state produced in the muscle or nerve by the interrupted current, throws it into healthy action. In disorders of the brain and spinal cord, the use of electricity is often followed by favorable results; while in certain forms of neuralgic troubles, like lumbago and sciatica, it sometimes affords speedy and permanent relief. In conditions attended with failure in respiration, as in poisoning by opium or impending heart-failure, life may be saved by exciting the muscles of breathing with a Faradic current. There are also conditions in which electricity has a general tonic effect on the whole system.

Physicians employ the electric light for illuminating the cavities of the ear, nose, mouth, throat, and stomach. Objects that could not otherwise be seen and investigated are thus brought into view.

A platinum wire heated to a white-heat by the galvanic current forms an instrument known as the galvano-cautery, of great service in the hands of the surgeon for the removal of tumors and diseased tissues. Electric engines are used both by surgeons and dentists to furnish the steady power necessary for the manipulation of instruments in delicate operations.

In order that benefit may be derived from electrical treatment, it must be applied by an experienced and careful practitioner. In the hands of the charlatan, electricity is an uncertain and even dangerous agent.

QUESTIONS.—What can you say of the production and control of Electrical Heating Effect? Explain the principle of the Arc Lamp. Why are carbons used, and how is the feeding of the carbons regulated? Describe the Incandescent Lamp, and illustrate the principle by diagram. Of what does an electric lighting plant consist? State the advantages of arc lamps; of incandescent lighting. Discuss the question of danger in connection with each.

Describe Electric Welding, and show what has been accomplished in this line. How has electricity been utilized for smelting and cooking purposes? Describe the process of Electro-plating. Explain the Storage-battery and its applications. What are the objections to Storage-batteries. State the uses of electricity in warfare; in medicine and surgery.

MISCELLANEOUS QUESTIONS AND PROBLEMS.

Assume that you have a lathe in your workshop, and half a mile away there is a small waterfall; describe a means of driving your lathe by this water-power. (*Suggestions: Water-wheel, small dynamo, wire to workshop, electric motor belted to lathe.*) The earth can be used as the return conductor by burying a plate at each end of the line.

If a ten-horse-power water-wheel is used to drive a dynamo, the current from which runs an electric motor half a mile away, what is about the maximum power that can be obtained from the motor? *About seven horse-power; because one horse-power would be lost in the dynamo, one on the line wire, and one in the motor, these losses being due to friction, heating of the wire,* etc.

Foucault revolved a copper disk between the poles of a strong magnet, and found a decided resistance to the revolution of the disk, although it did not touch the poles; the disk also became hot. Why? And why would such a disk become hotter than the armature of a dynamo which also revolves between the poles of a strong magnet? *The disk had currents generated in it exactly as in the armature of a dynamo, only in Foucault's disk the currents flowed round and round, thereby heating the disk; whereas in the armature of a dynamo the wires are separated by being insulated, which prevents these local currents between the different parts of the coil.* But if two parts of a coil cut through the insulation and come in metallic contact, causing a "short circuit," then that portion of the coil becomes very hot, like Foucault's disk.

If you wind an ordinary horseshoe permanent magnet with a number of turns of wire, the ends of which are connected with a galvanometer, and then alternately put on and pull off the keeper of the magnet, what effect will be produced in the galvanometer? *The needle will swing one way when the keeper is put on, and the other way when it is taken off, because of the generation of currents by the increase in the number of lines of magnetic force passing through the coil in the first case, and the decrease of lines of force in the second case.* This action is precisely like that of the Bell telephone when used as a transmitter.

What effect is produced on the light given by an incandescent lamp when the electro-motive force supplied to it is raised? If there is a great increase in light, why not always run incandescent lamps at a high electro-motive force? *The light increases very rapidly by increase of E. M. F., being doubled with only about ten per cent increase in electrical energy.* Unfortunately, the life of the lamp—i. e., the average number of hours it will burn without renewal—is greatly reduced when it is run at a high temperature, because of the deterioration of the filament; therefore a compromise is adopted, the proper point being that at which the lamp gives a *yellowish* and not a *bluish*-white light.

COMPARATIVE TABLE OF ENGLISH AND METRIC MEASURES.

MEASURES OF LENGTH.

Standard unit, one metre.

1 kilometre = 1,000 metres.	1 decimetre = 0·100 metre.
1 hectometre = 100 "	1 centimetre = 0·010 "
1 decametre = 10 "	1 millimetre = 0·001 "

---

1 metre = 39·37079 inches.	1 inch = 2·53995 centimetres.
1 decimetre = 3·93708 "	1 foot = 3·04794 decimetres.
1 centimetre = 0·39371 "	1 yard = 0·914383 metre.
1 millimetre = 0·03937 "	1 mile = 1·609315 kilometres.

To reduce kilometres to miles, multiply by ·62138.

MEASURES OF SURFACE.

1 sq. metre = 10·7643 sq. feet.	1 sq. foot = 9·28997 sq. dm.
1 sq. centimetre = 0·1550 sq. inch.	1 sq. inch = 6·45137 sq. cm.
1 sq. millimetre = 0·0015 sq. inch.	1 sq. yard = 0·8361 sq. m.

To reduce kilom-carrés (square kilometres) to square miles, multiply by ·386116.

MEASURES OF VOLUME.

1 litre = 1 cubic decimetre.
1 " = 1,000 " centimetres.

1 litre = 61·02705 cu. inches.	1 cu. inch = 16·38618 cu. cm.
1 cu. cm. = 0·06103 cu. inch.	1 cu. foot = 28·31531 cu. dm.
1 litre = 1·05672 U. S. qts.	1 U. S. qt. = 0·9469 litre.

MEASURES OF WEIGHT.

The unit, one gramme, is the weight of one cubic centimetre of distilled water, at the temperature of 4° C.

1 kilogramme = 1,000 grs.	1 decigramme = 0·1000 gr.
1 hectogramme = 100 "	1 centigramme = 0·0100 "
1 decagramme = 10 "	1 milligramme = 0·0010 "

---

1 kilogr. = 2·204621 lb. avoir.	1 grain = 64·799 milligr.
1 " = 32·15073 oz. troy.	1 oz. troy = 31·1035 gr.
1 gr. = 15·43235 grains.	1 lb. avoir. = 0·45359 kilogr.

One thousand kilogrammes varies but little from the "long" ton of 2,240 pounds avoirdupois (0·984206 ton).

The pound avoirdupois contains 7,000 grains.

The same figures which represent the specific gravity of any solid or liquid, referred to water as unity, also represent the weight of one cubic centimetre of the substance, expressed in grammes.

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